ARTICLE V.—The Library shall be divided into TWO CLASSES; the first comprising such works as, from their rarity or value, should not be lent out, all unbound periodicals, and such text books as ought to be found in a library of reference except when required by Committees of the Institute, or by members or holders of second class stock, who have obtained the sanction of the Committee. The second class shall include those books intended for circulation.

ARTICLE VI.—The Secretary shall have authority to loan to Members and to holders of second class stock, any work belonging to the SECOND CLASS, subject to the following regulations:

Section 1.—No individual shall be permitted to have more than *two books* out at one time, without a written permission, signed by at least two members of the Library Committe; nor shall a book be kept out more than TWO WEEKS; but if no one has applied for it, the former borrower may renew the loan. Should any person have applied for it, the latter shall have the preference.

Section 2.—A FINE OF TEN CENTS PER WEEK shall be exacted for the detention of a book beyond the limited time; and if a book be not returned within three months it shall be deemed lost, and the borrower shall, in addition to his fines, forfeit its value.

Section 3.—Should any book be returned injured, the borrower shall pay for the injury, or replace the book, as the Library Committee may direct; and if one or more books, belonging to a set or sets, be lost, the borrower shall replace them or make full restitution.

ARTICLE VII.—Any person removing from the Hall, without permission from the proper authorities, any book, newspaper or other property in charge of the Library Committee, shall be reported to the Committee, who may inflict any fine not exceeding twenty-five dollars.

ARTICLE VIII.—No member or holder of second class stock, whose annual contribution for the current year shall be unpaid or who is in arrears for fines, shall be entitled to the privileges of the Library or Reading Room.

ARTICLE IX.—If any member or holder of second class stock, shall refuse or neglect to comply with the foregoing rules, it shall be the duty of the Secretary to report him to the Committee on the Library.

ARTICLE X.—Any Member or holder of second class stock, detected in mutilating the newspapers, pamphlets or books belonging to the Institute shall be deprived of his right of membership, and the name of the offender shall be made public.

FIRST LESSONS

IN

METAL-WORKING.

BY

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OF "FIRST LESSONS IN WOOD-WORKING."

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PREFACE.

The first year of instruction in handicraft, as experience in the College of the City of New York has shown, may be given to wood-working or metal-working with about equal advantage. The minute accuracy, the acquaintance with geometrical construction, and the habits of neatness and cleanliness which are essential in the one are offset by the judgment, forethought, and artistic freedom of the other. Both constantly teach the lesson of orderly procedure, careful attention to instructions, and, where a text-book is used, of minute and thoughtful reading, such as takes in the full significance of every proposition and every limitation of it. The feeling of good-fellowship which results from struggling with the same difficulties, and occasionally, as in wood-working, and still more frequently, as in forge-work, lending a helping hand to each other, is a valuable part of the product of workshop training in either department. It has been the

author's practice therefore, for some time, to let a portion of each class begin in the wood-working shop, and another in the forge and vise-room. The advantage is thus secured of having both shops well filled; while otherwise, as the second year's class is always smaller than the first, one shop is overcrowded at the same time that the other is perhaps not more than half full.

The amount of knowledge of drawing required for these lessons is about the same as that given in the author's First Lessons in Wood-Working; so that if Metal-Working is taken up first, the student should be taught as much of the latter book as is found in Lessons VI, VII, and XXI.

Considerable thought and space have been given to the description and orderly development of the processes of manufacture of iron and steel, and of the annealing, hardening and tempering of the latter. The book being intended, not for those who are merely acquiring a trade, but for those who are learning to think, and to give clear expression to their thought, the lessons on this subject are intended to be thoroughly mastered, both by study and by practice, so that the student shall be able to explain, in good language, the reasons of the various processes he uses.

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First Lessons

in

METAL-WORKING.

LESSON I.

METAL-WORKING TOOLS. WROUGHT-IRON AND CAST-IRON. CUTTING AND BREAKING.

The tools used in cutting iron, like those used in wood-working, are wedges. They are thrust in or driven in between the particles of the metal, separating them from each other, making notches in the piece, and, if they penetrate far enough, tearing off chips or cutting the piece in two. Metal being much harder than wood, it is generally necessary to drive the cutting-tool forward by blows of a hammer, as is the case in wood-working also when the cut is deep or across the grain of the wood. When the metal and the tool can be held in powerful machines, such as the engine-lathe and the planing-machine, which you will understand by and by, a steady push can

be used, but without these, blows of a hammer are generally necessary.

Again, metal being much harder than wood, a different form has to be given to the cutting-tool. For wood-working the wedge may be thin, and therefore can be made to penetrate easily. The two faces of a knife, hatchet, or chisel make with each other an angle of about 25°, which is increased to 35° near the edge, by the sharpening of the tool on the oil-stone. Even this is sometimes found to be too small, and the tool splinters or "nicks" when cutting hard wood. For iron, therefore, the angle must be larger than this. It need not be much larger if the tool is not very brittle and if it is used only for cutting straight forward; but when the metal of the tool is very hard, or when the tool is strained crosswise in cutting, the angle must be larger, and is, in some lathe-tools, as great as 90°.

Again, metals being very hard, metal-tools are much heated if driven fast. It is a familiar fact that rubbing, compressing, or tearing asunder any material produces heat. Wood is heated by repeated blows of a hammer. In boring holes, the wood and the bit become hot. When the material worked is so hard as iron, if tools are pressed against it hard enough to cut it and then are moved rapidly, a great deal of heat is produced. In this case the heat may be enough to

soften and spoil the tool, and it is necessary therefore to work more slowly.

In metal-working there is no operation like that of splitting or hewing: chipping, which comes nearest to it, is considerably slower. In all metal-working, therefore, the pieces are fashioned nearly to the desired shape while they are soft, and the work which the cutting-tool has to perform is thus lessened. There are two ways in which the metal is thus prepared—casting and forging.

Casting is melting the metal and pouring it into moulds of the proper shape. In this case heat performs the greater part of the work. It separates the particles of the metal from each other so that they can flow into every corner of the mould, and the workman has then only to finish the surface of the casting with suitable tools.

Forging is hammering the metal while it is soft. All metals melt when heated. The temperature for melting ranges from about 450° F. for tin to about 4500° F. for platinum. Before reaching the melting-point, the metal becomes soft, and, while in this state, if two perfectly clean surfaces are brought into close contact, they adhere and the two pieces become one. This process is welding. While in the soft state also, a metal can be hammered into almost any desired shape. This process is forging. The two processes of forging and welding are generally in-

cluded under the term "forge-work" or "forging." They are applicable, as casting is, to various metals; but all three are important chiefly in the case of iron and steel, because of the ease with which the operations can be performed, and the abundance, cheapness, and strength of the metals.

The iron used for casting, or foundry-work, and that used for forge-work, are called respectively cast-iron and wrought-iron. Cast-iron is iron combined with carbon; wrought-iron is the same metal after as much as possible of the carbon is removed. We will begin our exercises in forge-work by studying some of the differences between them.

Examine the two specimens of iron on your anvil. Holding each loosely between the fingers, strike it on the edge of the anvil. Observe the ringing of the one and the duller sound of the other. Strike them on the edge with the edge of your hammer, and observe the difference in the character of the nick. Lay them on the anvil, and hammer them pretty vigorously at one end. One flattens, the other does not; one is malleable, the other is not. When you have learned to use the fire, repeat this last experiment while the pieces are red-hot, and you will find the difference greater still. Lay them across two supports, about 3″ apart on the anvil, as in Fig. 1, and

strike them with the hammer (being careful not to stoop over them, lest they fly up and hurt you).

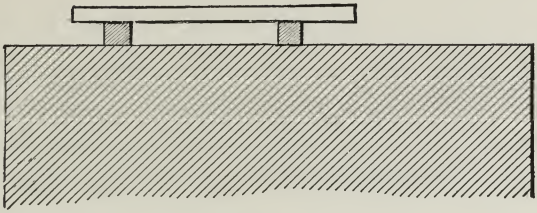

FIG. 1.

One bends, the other very probably breaks.* Next try to break the bent one: you find this difficult. At one end of the anvil is a chisel, called the "hardee" or "hardy," meaning "hard edge," being made of steel, and hardened on the edge. Lay the unbroken piece over this, and strike it two or three times with the hammer, making a nick in it. Be very careful not to strike the hardy with the hammer. Turn the piece over, and nick the other side, exactly opposite the first notch. When you have cut it thus, you will find that you can break it by laying it over the two supports, and

Exercise 1. Cutting with the hardee.

* The same experiment may be made with less risk of injury from the flying fragments when the piece breaks, by holding each piece in the vise while striking the blow. Let it project three or four inches above the vise. Strike *from* you, towards the wall behind your bench, so that, if the piece flies off, it will hit no one. Or, still more safely, the pieces may be bent by holding them at the ends in a suitable clamp, and pressing them down at the middle by a screw.

striking it at the nick, or even, if it is notched pretty deeply, by laying it over the edge of the anvil, and striking it just beyond the notch, or holding it in the vise, just below the notch, and striking at the end. The tough piece is wrought-iron; the brittle piece is cast-iron. Make a written memorandum of all the differences between them that you can discover, including the difference between the surfaces of fracture examined with a lens.

LESSON II.

CARE OF FIRE. DRAWING AND POINTING.

When an object is made of wrought-iron, it must be made as nearly as possible of the right shape at first, by forging, so that it may require little or no finishing with cutting tools. Forging, or shaping with the hammer, includes a number of distinct operations, called drawing, pointing, upsetting, bending, twisting, punching, and welding. In nearly all of these the first step is to make the metal red or white hot, and in doing this the proper management of the fire is of the highest importance.

Your forge has a broad "hearth," on which coal can be heaped up over the mouth of a pipe called the "tuyere" (pronounced twee-er). Through this tuyere a current of air can be forced from the bellows or blower. With a moderate supply of air the fire burns slowly, and produces a temperature of about 800° or 900° C., equivalent to about 1500° to 1700° F. Every atom of oxygen that unites with an atom of carbon in the coal produces a certain amount of heat; hence the more carbon and oxygen used, the more heat produced. With a good supply of air you can raise

your fire, and any piece of iron in it, to about 1500° C. or 2700° F. It is possible, however, to furnish more air than the carbon requires for its combustion. The air then only cools the carbon, or tends to blow out the fire. A lighted stick thrust into a bottle goes out for lack of oxygen. A lighted match goes out in a strong draught because of excess of air. Remember this in managing your fire.

Exercise 2. Making a fire.

To start your fire, place a small heap of shavings over the throat of the forge. Light it, and when it is blazing, scrape a few pieces of coke or coal over it, choosing such as is free from large lumps. As these light, scrape on more, blowing gently with the bellows. Gradually cover completely, and blow harder. Sprinkle with water the coal round the outside of the fire, which will prevent the fire from spreading too far, and will also make coke for the next day. When once started, the fire can be kept covered and burning slowly for a long time, by leaving a stick of hard wood in it, or can be blown up in a few minutes to a white heat.

Exercise 3. Heating to a white heat.

For your first exercise in forging, cut off a piece of $\frac{1}{4}''$ round iron, exactly $20''$ long. If you fail to cut it exactly right, make a memorandum of the length in your note-book. We will now make a square point two inches long on the end of this. Put the end

in the fire, covering it lightly with the coals. It is best, particularly in working such thin iron as this, not to bury it very deeply in the fire, but to keep it near the surface, where it can be watched through the spaces between the coals, and removed as soon as it reaches the proper heat. If left too long in a very hot fire, and with a plentiful supply of air from the bellows, the iron may burn and the piece be spoiled; for iron is combustible, just as wood and coal are, only it requires a higher temperature to burn it. With larger pieces, such as you will have in later exercises, this accident is less likely to happen. Watching your iron, you will see the black rod get gradually red and then white, so as to be indistinguishable in the midst of the glowing fuel. In this condition it will burn if left too long. Remove it from the fire by the cool end, which will be cool enough if you have not thrust it in too far, or left it too long. It should be white-hot just at the end, and red about two inches farther. As you carry it through the air, brilliant white sparks will shoot off from it, if it is at a good white heat: these are particles of iron burning. Lay it, without loss of time, on the anvil, so that the hot end rests on the farther edge, the end in your hand being raised three or four inches, so that the bar is inclined to the face of the anvil. Hold the hammer with its face

Exercise 4. Drawing and pointing.

similarly inclined. Grasp it firmly, with the fingers under the handle and the thumb extending along the top. Then, with quick light strokes, not *near* the end, but at the very tip, beat the iron out, turning it to and fro through a quarter turn after each blow or two, so as not to flatten it, but to make the end square and pointed. When a little of the end is pointed, you may gradually work farther back, till you have produced a square point two inches long. Be careful not to continue hammering, particularly at the point, after the iron has lost its bright white heat. If you do this you will probably split it. Wrought-iron, as we shall see later, is fibrous in structure, and the fibres, like those of wood, can be torn asunder more easily than they can be broken across. This splitting is especially liable to happen in inferior iron, just as it does in wood that is wanting in toughness, and affords one means of judging of the quality of the iron. If your rod does split at the end, you can generally get the parts to reunite, by raising it again to a white heat, and hammering gently. This operation is assisted by sprinkling the piece with white sand when you take it from the fire, and putting it back in the fire a few minutes before hammering it. If you do not succeed in closing the split, you must cut off the cracked end on your hardy and begin

again, being more careful now to keep the metal at a bright red heat when hammering near the end, reheating it for this purpose several times if necessary.

In turning the piece to and fro while hammering, you must be careful to give it just a quarter of a turn each time; otherwise you will give it the

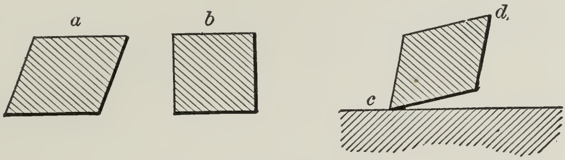

FIG. 2.

cross-section *a*, Fig. 2, instead of *b*. In this case you will have considerable trouble to restore the proper shape by holding it on the anvil as at *c*, and striking it at *d*.

When you have pointed the piece and cooled it, measure its length, and compare it with the length it had at first. The lengthening of a piece by hammering is called drawing. Observe how much you have drawn this, making allowance for any that you may have cut off because of splitting. It is important that you should learn to estimate the amount of drawing in any particular case in order to be able to make allowance for it in future work. Of course this lengthening cannot be accomplished without reducing the diameter, either, as in this case, at the point, or at some other place,

or along its whole length. This last is what takes place in making "bar-iron." A short thick mass of iron is passed, while white-hot, between strong rollers such as are shown in Fig. 52. As the iron passes through the successive grooves, it is reduced in thickness and increased in length, and comes out at last as bar-iron, of the same size and shape as the last groove.

LESSON III.

BENDING. TURNING AN EYE.

Having drawn and pointed the rod, form an eye on it, as in Fig. 3. The eye, being 1″ in diameter, will be nearly $3\frac{1}{4}$″ in circumference.

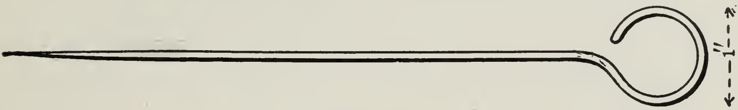

Fig. 3.

Heat about $3\frac{1}{2}$″ of the end of the rod to a bright *red* heat. Lay it over the edge of the anvil, with one of the flat faces of the point turned up, and bend it down at right-angles with a few gentle blows of the hammer.

Strike at *a* and *b*, Fig. 4, alternately, striking

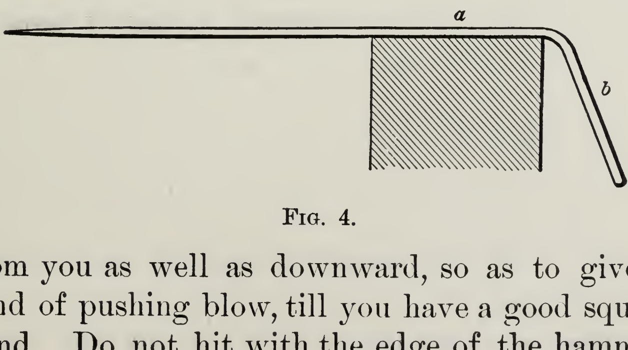

Fig. 4.

from you as well as downward, so as to give a kind of pushing blow, till you have a good square bend. Do not hit with the edge of the hammer, nor hard enough to bruise the iron.

Next place the part *b* on the "horn," or round end of the anvil, as in Fig. 5, and bend it round as at *c* and *d*, nearly closing the ring. Then, laying the part *bc* on the edge of the anvil, the

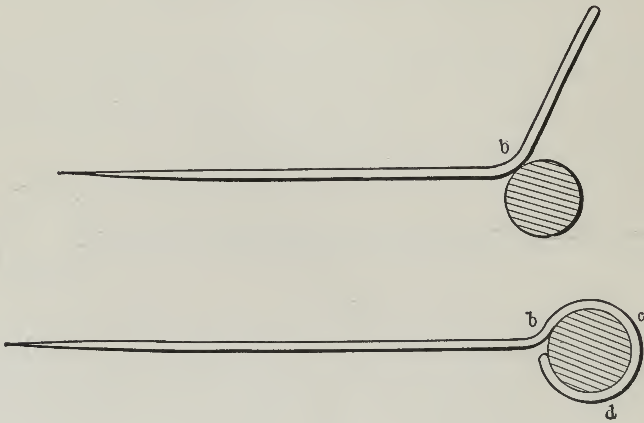

Fig. 5.

point *d* being upward, and striking lightly at *d*, close it. Be careful to make the ring as nearly as possible circular, perfectly closed, and symmetrical on the stem, as at *f*, Fig. 6, not one-sided, as at *g*. The last part of the eye, near the point of closing, must be bent with the tail or "pene" of the hammer. If you do not succeed the first time, heat the eye again, spread it out by driving it on the horn of the anvil, and repeat.

Exercise 5. Bending.

If the eye closes too far down on the stem, as at

a, Fig. 7, open it on the horn, and then bend it to the proper shape with light blows of the tail of the hammer at *b*, while resting on the horn at *c*. If it closes too far up, as at *d*, strike at *f*, while resting on the horn at *e*. If the iron gets too much burned, you must cut it off on the hardy

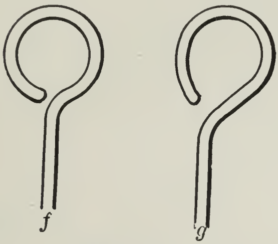

Fig. 6.

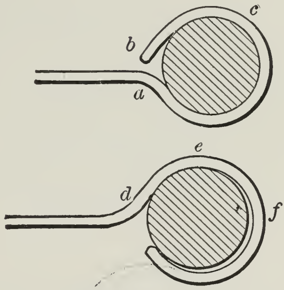

Fig. 7.

and begin again; but this ought not to occur, as it spoils the proportions of the piece.

Exercise 6. A forge-poker.

Use the eye already formed, if it is a good one, cutting off the square point on the hardy. If it is not good, cut off another piece of bar-iron of the proper length, and form a new eye. Flatten the rod for about 4″ from the end, to a width of about $\frac{3}{8}''$, which will give a thickness of about $\frac{1}{8}''$. In flattening, or in any operation in which much hammering is to be done on one piece, do not move the hammer about on the anvil, but let it fall constantly on the same point, about the middle of the face of the anvil, and move the iron

instead of the hammer. This principle is even more important when two persons work on the same piece, as in some later exercises. Hold the rod so that the plane of the flattened portion shall be perpendicular to the plane of the eye. In this, as in Exercise 4, page 10, begin hammering at the tip, and with a good bright white heat, so as not to split the rod. Having flattened it to the proper amount, hammer it cold, to smooth it. Heat it again, lay it over the edge of the anvil and bend it at right angles at *a*, Fig. 8, as in Exercise

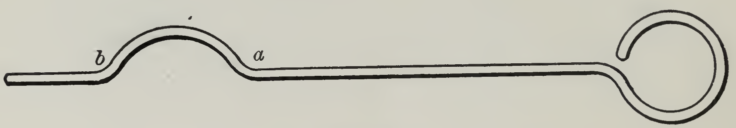

Fig. 8.

5, Fig. 4. Lay it across the horn and bend the curved part *ba*. Again lay it on the edge of the anvil as at *c*, Fig. 9, and form the straight end as at *d*. The plane of the bend should be the same as the plane of the eye. Look along the rod and test this. See also whether the rod is straight, and whether the plane of the short flattened piece at the end is perpendicular to the plane of the bend and the eye. Correct any crookedness by

gentle blows while the iron is cooling. If the plane of the flattened portion is not perpendicular to the plane of the ring and of the curve *ab*, heat the straight part near *ab* to redness, place it on

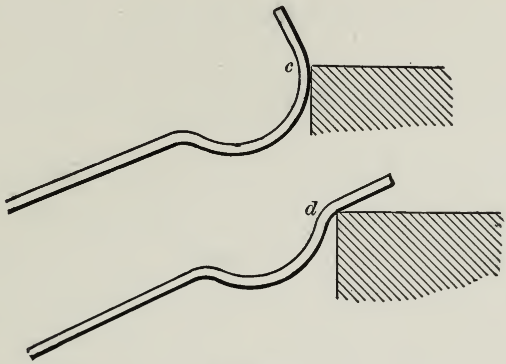

Fig. 9.

the anvil so that the eye is perpendicular to the face of the anvil, and strike a light blow or two at *b*. Or hold the ring in the vise, and, taking hold with the tongs at *b*, twist the rod to the proper position.

LESSON IV.

FLATTENING, PUNCHING, AND BENDING.

WHILE iron is soft it is easy to make holes in it of any desired shape, with a steel punch.

We will make an "angle-iron" or "bracket," Fig. 10, from a piece of $\frac{3}{8}''$ round iron 8″ long.

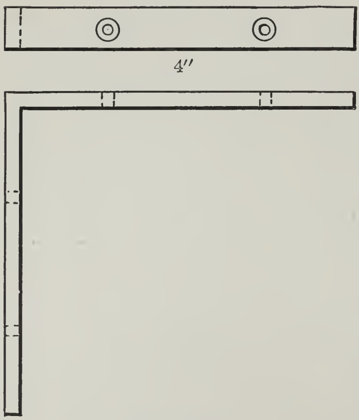

FIG. 10.

This is to be first hammered out flat to a width of $\frac{1}{2}''$; secondly, bent at right angles; and, thirdly, punched with four holes for screws. Take a piece of iron 16 long. For the first operation, heat one end of the piece to whiteness, and, beginning as in Exercise 4, page 10, at the end, and with the same care to prevent splitting, hammer it down to the thickness of about $\frac{1}{4}''$. Then, working from the end towards the middle, flatten about 4″ of the piece, working always on the centre of

the anvil, as in Ex. 6. Be careful not to hammer more on one edge than on the other. If you do you will bend the piece. If, for instance, you hammer too much on the right-hand edge, you will make this edge not only thinner, but longer than the other, and will thus make the piece bend towards the left. If you find this happening, you can correct it by hammering a little more all along the left-hand edge, or wherever you find it thicker than elsewhere. Turn the piece over occasionally, and hammer on the other side to prevent the end from turning up. Heat about four inches more of the bar, and flatten in the same way the rest of the 8″ that will be required. Do not extend the flattening more than about a quarter of an inch beyond the required distance. The remainder of the metal was only left as a handle to hold the piece by, and when you have finished, is to be cut off and left undefaced for future use.

The piece is now of the uniform width of ½″ straight and uniformly thick, and is ready for bending and punching. Before bending, bevel the edges slightly on the side where the heads of the screws will be, by hammering, cold, on the anvil. Mark with a centre-punch, Fig. 11, B, the place at which the bend is to be made. Heat the piece to a red heat at this place, lay it on the anvil with the mark exactly over the edge, and, while an assistant holds a hammer on the piece

just behind the mark, bend it at right angles. Or, hold it in the vise at the mark and bend it.

Exercise 7. Punching.

For punching, use a slightly tapering punch, Fig. 11, A, about $\frac{1}{16}''$ in diameter at the point, and not more than $\frac{1}{4}''$ at one inch from the end. Having marked with a centre-punch the places where the holes are to be made, lay the piece, heated to a bright red, on the anvil, and drive the punch half-way through. The piece, when turned over,

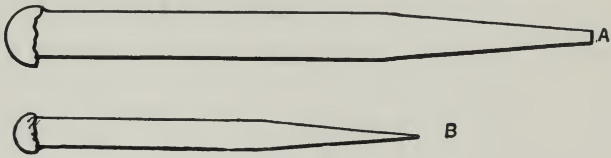

Fig. 11.

will show a dark spot due to the cooling effect of the punch. Apply the punch here and drive it through from the other side, pushing out the small piece or burr by driving it into one of the holes in the anvil. Be careful not to drive your punch in too far, or you will spread the hole too wide, and may split the piece. Drive it so far as to enlarge the hole enough for the admission of the screws that are to be used in putting up the bracket. If these are "round-headed" screws, Fig. 12, A, this is all that it is necessary, except to smooth and straighten the piece where it may have been bent. If they are "flat-headed," Fig. 12, B, the holes must be "counter sunk," that is,

enlarged at the top, as in Fig. 13, to correspond with the head of the screw, and let it come even or "flush" with the surface of the iron. When only a shallow countersink is required, it may be made with a countersink-punch, Fig. 14, A; but to cut deep

Exercise 8. Countersinking.

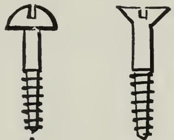

Fig. 12.

Fig. 13.

enough to let the head of a screw come even with the surface of the iron, a countersink-bit, Fig. 14, B, must be used, as in wood-working.

When you have made and countersunk the holes, finish the piece as straight and smooth as you can, cold. Finally, cut it off at the proper point, and bevel the newly cut edge like the others. When finished, the bracket should be true to the proposed dimensions, exactly right-angled and free from "winding," smooth and without marks of burning, square at the ends and equally bevelled all round, and the centres of the holes should be in a line exactly parallel to the edges.

Fig. 14.

LESSON V.

BENDING, POINTING, AND TWISTING.

Remembering how much the iron was drawn in Exercise 4, provide a piece of $\frac{1}{4}''$ round iron of the proper length for the exercise shown in Fig. 15.

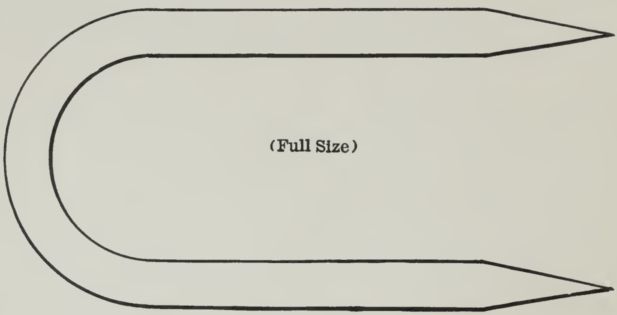

Fig. 15.

Keep a memorandum of the length provided, and test the correctness of your estimate by comparison with your finished work at the end of the exercise.

The iron in this exercise being short, will have to be held with the tongs. Point both ends of

the piece, as in Exercise 4, with the precautions there indicated. Make the flat surfaces at the two ends to match. Heat the piece at the middle and bend it over the horn of the anvil. Attend to the following points:

Exercise 9. A staple. Use of the tongs.

1. Hold the tongs so that the opening between the jaws shall be horizontal. One of the jaws will then be over the piece you are holding, which will then not be so easily knocked out of the tongs as if the opening were vertical.

2. Let the bend be in the plane of two of the squared faces.

3. Make the bend as nearly as possible in the middle.

In making the bend you will probably bring the points too near together; in fact they may almost meet. To separate them, drive the staple

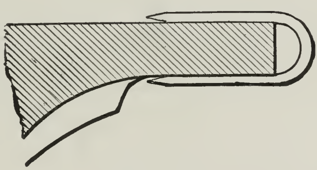

FIG. 16.

down on the hardee, so that the latter shall spread out the legs. If they are not quite equal, make them so by striking gently on the curve while holding the staple upright with the point of the long leg resting on the anvil. Straighten the

legs by thrusting the thin end of the anvil between them as in Fig. 16, and hammering lightly first one and then the other. Lay the staple on the anvil and see that the legs lie in the same plane, both touching the face of the anvil in their whole length. If they do not, hold one end in the tongs and strike the other near the top or circular end till you correct the winding or twist; or you may hold one end in the vise and bend the other to the proper position with the tongs, or, when cold, with the fingers. Examine the curve carefully for any lack of symmetry, and correct it by gentle blows over the horn of the anvil. Finish it smooth when cold. Do not neglect to compare your finished work with your estimate, so as to learn how much to allow for such objects in the future.

Exercise 10. An S-hook.

Each ring in this exercise being $1\frac{1}{4}''$ in diameter, the circumference will be $3\frac{1}{7}$ times $1\frac{1}{4}''$, or about $4''$, and both together about $8''$. A portion of the iron, about $\frac{1}{4}''$, at the middle, belongs to both rings. Deducting this, and about $\frac{1}{2}''$ to $\frac{5}{8}''$ at each end for drawing, leaves about $6\frac{1}{2}''$ as the length of the piece of $\frac{1}{4}''$ iron needed for the job. Holding the piece with the tongs, point each end, as in Exercise 4, but round instead of square. It will be a useful exercise, and will assist you in rounding the iron symmetrically, to make it first square,

then octagonal, and then round. Do not make the points too long. If the taper extends beyond *a*, Fig. 17, it will weaken the hook. Be careful not to burn the points. Finish them smooth, cold. Then, heating one end to redness, lay it on the horn at the middle of one half, or a little nearer to the middle of the piece, as at *o*, Fig. 18, and turn it as in Exercise 5. Having formed one eye, heat the other end and form the other in the

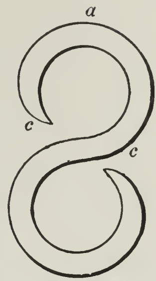

Fig. 17.

Fig. 18.

same way. The points of the hook should be bent down almost to the stem, as at *c*, Fig. 17, leaving an opening of about $\frac{1}{8}''$. Both eyes should be exactly circular and equal, the hook appearing as in Fig. 17, not as in Fig. 19, where *ab* is too nearly straight, and the eyes are too pointed at *c*.

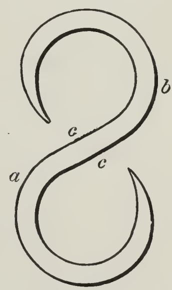

Fig. 19.

You have now discovered that forge-work requires more judgment by the eye than wood-work. It is not possible to mark out your work with rule and square. You must estimate without the

help of these tools, and must make allowance for changes of size which the pieces undergo in drawing, and in other operations to be described hereafter.

Estimate the quantity of iron needed for the hook, Fig. 20, making allowance for the length gained in drawing, and cut off a suitable piece.

Exercise 11. A long hook.

Then proceed as follows: First draw and round the point as in the last exercise. Next bend at right-angles at *a*, as in Exercises 5 and 6. Then turn the curve *b* over the horn of the anvil, and form the flat curve *c*.

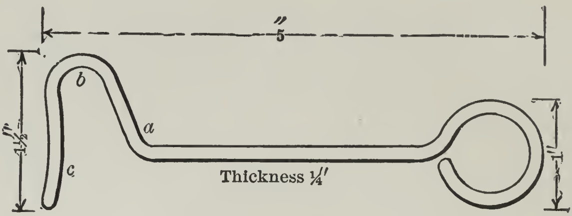

Fig. 20.

Lastly, form the eye as in 5 and 6, being careful to have it in the same plane as the hook, and circular, and symmetrical on the stem. In all these exercises care must be taken to keep the iron hot enough to work easily, but without burning it. A bright white heat is needed for drawing and pointing, and a good red heat for the rest of the work. In all the operations also, care is to be taken not to mar the cylindrical form of the

iron by hammering too hard; and in all of them, any parts that have been roughened by the heat should be hammered cold to smooth them, but not so hard as to injure the iron. Examine your work critically, looking along it to test for winding, and not accepting it as finished so long as there is any particular in which you can improve it. Finally, compare its dimensions carefully with those of the working-sketch, so as to learn whether your allowance of metal was correctly made.

Exercise 12. A twisted hook.

The following is a variation of the last exercise, involving squaring and twisting. The dimensions are given in centimeters. The thickness of the iron may be the same as in the last exercise. After pointing the rod, form the hook and the eye as in the last exercise. Then square the part *ab*, Fig. 21, with

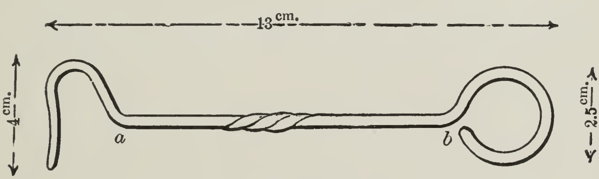

Fig. 21.

the same precautions as in Ex. 4. Finish the square part cold, with good sharp edges. Then heat to redness, and cool both ends in water, leaving about $2\frac{1}{2}''$ in the middle bright red (not

white, which would soften the iron too much). Holding it upright in the vise by the lower end, take hold of the other end with the tongs, and twist it round rather slowly, through exactly two turns, leaving the plane of the eye coincident with that of the hook. Be careful not to bend the stem in twisting it, as it will be hard to straighten it without defacing it.

LESSON VI.

WELDING.

WELDING is joining two pieces of metal which have been made soft or pasty by heat. Wrought iron, if of good quality, comes to this condition at the temperature of about 1500° C, or about 2700° F. This temperature is called the "welding heat," and may be recognized by the dazzling white light that the iron gives off, and the vivid sparks that fly from it as it is carried through the air to the anvil. If the iron is not of good quality it may be made brittle by heat. Such iron is called "hot-short" iron. No such iron must be used. Indeed, it is hardly possible to use it, but valuable time may be wasted in trying to do so. Iron which breaks under the hammer when cold is called "cold-short."

The sparks given off by iron at the welding heat show that it is burning, and therefore wasting away. This high temperature therefore must not be used, except when it is absolutely necessary, as in welding; all other operations of the forge are performed at a "white heat," a "bright red or cherry red," a "low red," or even a "black red," which is only visible in a dark place.

When two pieces of wrought-iron are to be welded together, they must both be brought to the welding heat; and they ought to reach that heat at the same time, otherwise one may be burned before the other is ready. They should therefore be heated in the same part of the fire, and should be watched, and if necessary moved about, to let each receive its proper amount of heat. When at the welding heat, they must be put together as quickly as possible in the proper position, and made to adhere by a few light blows of the hammer, after which harder blows are given till the union is complete.

To hold the two pieces in the proper position and manage the hammer at the same time is often difficult, and, even if the pieces are not very large, generally requires the hands of two men, unless

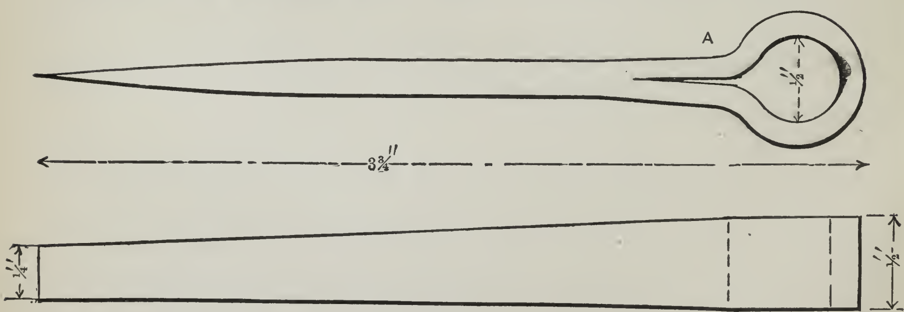

FIG. 22.

some device be used for fastening the two pieces together. We will therefore begin our exercises in welding with such as consist in joining the

ends of the same piece, and so do not require an assistant. The forging of an old-fashioned eye for a gate-hinge, Fig. 22, is such an exercise. To make the piece of the dimensions indicated in the figure, cut off a piece of $\frac{3}{8}''$ round iron $5''$ long.

Exercise 13. Flattening and drawing.

This is to be first flattened and shaped as shown in Fig. 23. The drawing of the ends must be done at a red heat. If a white heat is used it will be harder to make the weld afterwards. Turn the piece over frequently

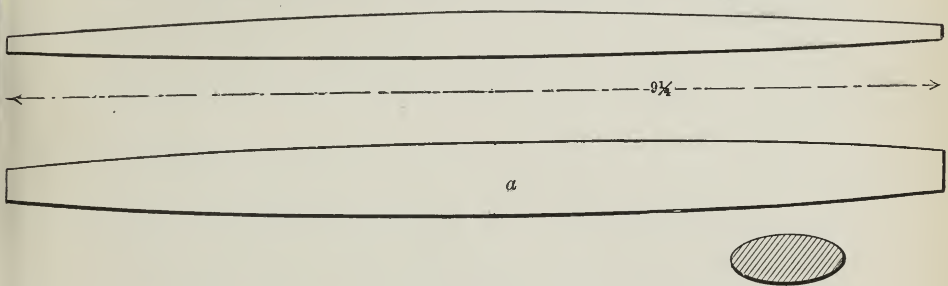

FIG. 23.

while working it, to keep it straight. Do not make it too thin at the ends. When flattened, it should have in the middle the shape and size shown in the section, nearly, being flattened less than it will be in the finished job, for fear of weakening it too much, and increasing the risk of burning. Reheat the piece as often as may be necessary, but take care not to burn it. If you are pretty skilful, one or two heats will be enough to bring it to the proper shape. Hammer the edges square, keeping the

Exercise 14 An eye for a hinge.

corners sharp and smooth: good edges are as essential to fine workmanship in metal as in wood.

Next, heating the piece to a dull red at the middle, hold it at one end with the tongs, and bend it round the horn of the anvil till the two parts are parallel and equal, as in forming the staple, Exercise 9. Put a piece of $\frac{3}{8}''$ round iron in the bend, and hammer the two parts close together, as at *a*, Fig. 22, laying the piece on the anvil with the eye overhanging the edge, and striking lightly with the tail or "pene" of the hammer. The two parts must be in as close contact with each other as possible, otherwise dirt will get in between them, and may spoil the weld.

The piece is now ready for welding. Raise it to the welding heat. It is very essential for this operation that you should have a good bright fire, made of fresh coals, free from the burnt-out cinders on the hearth. These will not burn well enough to secure a good welding heat, and besides will make the surface dirty. The throat of the forge also must be cleared of the solid cinder which forms there, and the fire must be deep enough to contain a good body of coals under the iron as well as over it. When the piece is at a dazzling white heat and throws off brilliant sparks in the air, place it, with the least possible loss of time, on the anvil, and hammer it quickly with moderate force and beginning at the point, till it

is welded to within about $\frac{1}{2}''$ of the eye. Heat the eye to a dull red, drive in a round tapering punch $\frac{1}{2}''$ in diameter where thickest, and hammer harder, at a dull-red heat, to flatten the metal here and smooth the eye inside and outside. If you have not a proper punch, make one, from a piece of $\frac{1}{2}''$ round iron by drawing and pointing it slightly, as in Exercises 4 and 9. If the eye is too pointed at the base, close it by hammering on the edge of the anvil with the tail of the hammer while the punch remains in place. The eye should be perfectly round and smooth. Finish the shank straight, square, and smooth, and draw the tip down to a sharp point. Compare your finished work with the figure, observing how much you have departed from the proposed dimensions. If your piece has turned out too short, it is because you have burned it, or not drawn it out enough, or both. Ascertain the cause of your error, and work closer the next time.

LESSON VII.

UPSETTING AND WELDING.

The next exercise, the forging of a link of a chain, is similar to the last, in that the two surfaces of the weld belong to the same piece, and thus again the need of a helper is avoided. The weld, however, is much shorter, and so the surfaces of contact are smaller. Besides, as the link of a chain is subject to great stress, it is even more important in this case than in the last, that the union of the two parts should be perfect. This therefore will be a more difficult task than the last.

Use the piece of $\frac{1}{2}''$ iron, 8″ long, left from Exercise 7. The joint is of the form called a scarf-joint, and is shown in Figs. 25 and 28. The surfaces may be prepared either before or after bending the piece, but it is somewhat easier to make them fit together well if prepared afterwards. It will be necessary, however, to provide against the waste which will occur at the joint by thickening or "upsetting" the piece at the ends. This is an operation which has often to be performed as preliminary to others. It may be done either before or after the bending. To perform it before bending, heat

Exercise 15. Upsetting.

about one inch of the end of the bar to whiteness. If much more than an inch is heated, cool it, by immersing the bar, up to within about an inch of the hot end, in water. Then "upset" the piece either by striking the hot end on the anvil while holding it upright in the tongs, or by standing the piece upright on the anvil, holding it with the tongs with the hot end up, and striking the latter with the hammer. In either case the blows must not be too hard or the piece will bend. The same will happen also if too much of the length of the piece is heated. If the piece does bend, it must be straightened before going any farther. If the hammering turns the metal over too much on the edge, lay the piece on the anvil and hammer it gently on the sides, but only enough to smooth the ragged edge, without reducing the end to its original thickness. When properly upset the end should appear as in Fig. 24. After upsetting one

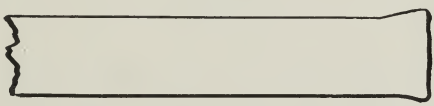

Fig. 24.

end, cool it, and then heat and upset the other. It is obvious that this operation, besides thickening the bar will shorten it. You ought to measure and keep a memorandum of the amount of this shortening, so as to know how much to allow for

it in other cases, when it may be necessary that the bar should have exactly a given length. In the same way that a piece is upset at the end, it may, when necessary, be upset at the middle, by heating at the middle only, and hammering on the end lengthwise.

The ends being now upset, bend the piece to a U-shape. It is then ready for the formation of the joint.

The scarf-joint consists, as the figure shows, of an indentation in the end of each piece, into which the end of the other piece fits. These indentations are not made, as in wood-working, by cutting out

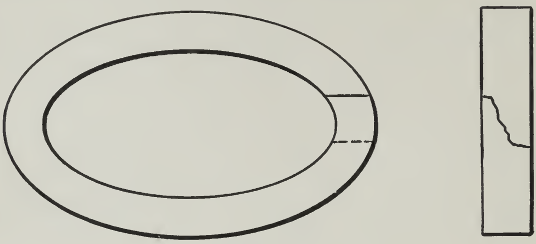

FIG. 25.

some of the material, but by hammering it so that it spreads out sideways and endways. Neither should they, as in the case of the joint in wood, be cut to half the depth of the piece, but less. It will thus result that when the two ends are put together, the piece will be wider and thicker at the joint than elsewhere. This extra thickness will disappear as the weld is hammered, and if the

quantity of metal has been correctly estimated, this part will be at last neither thicker nor thinner than the rest.

To prepare the scarf, heat the open end of the U-shaped piece to a white heat. Lay it on the anvil and make a bevel at one end, with the face of the hammer, as in Fig. 26. This will still fur-

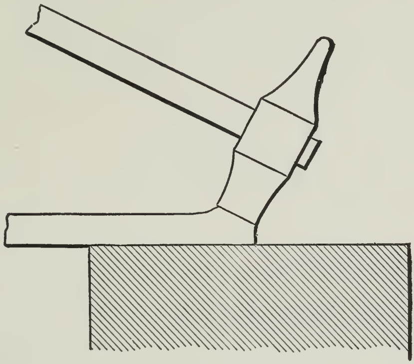

Fig. 26.

ther upset the piece at the upper edge of the bevel, as shown in the figure. Then, using the pene of the hammer, as in Fig. 27, give the piece the form shown, enlarged, at *a*. The surface need not be smooth. It is indeed preferable that it should be formed of small ridges or steps as shown. Heat the other end of the piece and treat it in the same manner, but on the other side. One heat will be sufficient for the preparation of both ends if you work quickly, but there will be no harm in heating several times, if you are careful not to

burn the piece. The pieces will have been widened in the process of scarfing, and are to be brought back partly to their original width, by hammering on the sides. There should be, however, some extra width left, to make up for the loss by burning, of which there will be some in spite of all the care that can be taken. When finished, the scarf will present the appearance shown in plan and elevation in Fig. 28.

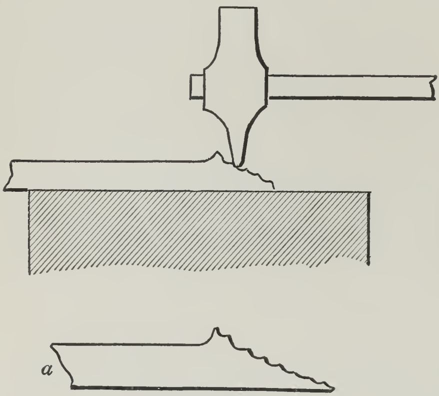

FIG. 27.

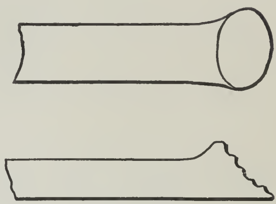

FIG. 28.

When the scarf has been thus prepared, bend the ends of the V round over the horn of the anvil as in Fig. 29, till they meet and overlap, as in Fig. 30, and hammer them, at a red heat, now on the face of the anvil and now on the horn, till they fit together closely. You are now ready for the welding.

For this make sure, as in the last exercise, that you have a hot fire of good coals, and get a thor-

ough good welding heat, without burning. There is special danger of burning in exercises like this, in which the piece is small, and has a thin edge.

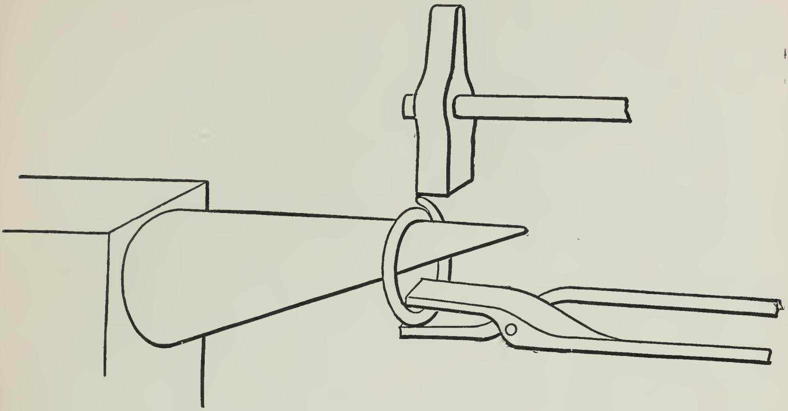

FIG. 29.

As soon as it shows, by the vivid sparks which it emits, and by its intense whiteness when viewed through the chinks in the fire, that the proper heat has been reached, place it as quickly as possible on the anvil, and hammer the parts together by quick light blows. When they have adhered,

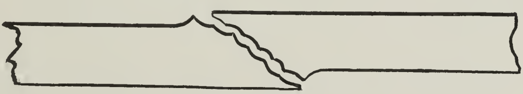

FIG. 30.

the extra metal produced by the upsetting and scarfing may be hammered down on the horn of the anvil, and the link brought to its proper shape, more at your leisure and at a lower heat.

In this exercise, and in general in all welding operations, it is necessary that the surfaces of contact should be quite clean, or if there is anything on them, it should only be something fusible, which will squeeze out under the blows of the hammer. Coal-dust will generally burn off and not give much trouble. Cinders, if your fire should be so "dirty" as to allow any to settle on the joint, which ought not to happen, can often be shaken off by a sharp blow on the edge of the anvil. The oxide of iron also, in the intense heat of the welding fire, is generally driven off as fast as it is formed. But while the piece is exposed to the air on the anvil, and on its way there, some oxide of iron is formed which is not got rid of, but which falls off under the blows of the hammer, and is found on the anvil as black scales. If any of this forms on the surfaces of contact, or if any cinder is held between these surfaces during the welding, the iron will not adhere well, and the weld will fail. This therefore is another reason why you should work quickly at this stage.

This oxide of iron, when its formation cannot be prevented, is removed by the use of white sand or borax as a "flux," that is, a substance which unites with the oxide and makes a sort of glass, which is fusible and is squeezed out by the hammer. With good wrought-iron the flux is not generally necessary, provided a true welding heat

is used and the work is done quickly. With steel, as will be seen hereafter, it is indispensable. When a flux is used with wrought-iron, it is to be sprinkled on the joint, or the iron is to be plunged in the flux, but only at the welding heat. At a lower temperature the sand will not adhere and melt, and will do no good. At the welding heat it melts and spreads over the surface, partially protecting it from the air, and allowing it to be raised to a higher temperature without burning so much. When it is put into the fire again, the brilliant white sparks still appear, and as it is carried to the anvil it will give forth a hissing noise. When this happens you are pretty sure of a good weld if you work quickly.

The form of the joint is important also, with

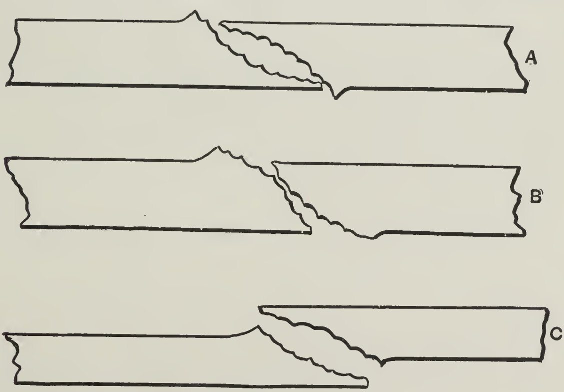

Fig. 31.

reference to the escape of impurities. If the surfaces of the scarf are concave, as in Fig. 31, A,

the welding takes effect first at the two points of contact shown, and some of the impurities may be imprisoned, and prevent a good union of the pieces, though in general they will escape sideways, particularly if the surfaces are small. If the surfaces are convex, as at B, they touch at first only at the middle, and there is sure to be plenty of opportunity for the impurities to escape, however large the surfaces may be. The same result is secured nearly as well if the surfaces at A are put together in the manner shown at C.

It is desirable that the weld should be accomplished at a single heat, because in reheating the danger of burning is increased; but you must not, merely to avoid this risk, allow an imperfect weld to pass.

Inspect your work critically when done. It should show the following appearances:

1. The weld should be invisible.

2. The iron should not be burned away at the thin edges of the scarf, leaving little notches; yet this is a less serious fault than if the scarf itself is visible as a fine crack for the whole or a part of its length.

3. The ring should not be any thicker at the weld than elsewhere, nor any thinner,—which is more likely to happen, and is a more serious fault.

4. The iron should be of circular cross-section throughout, and without bruises.

5. The link should be a perfect ellipse, and with the 7-inch piece of iron that you have used, should be of the exact size and shape of Fig. 32.

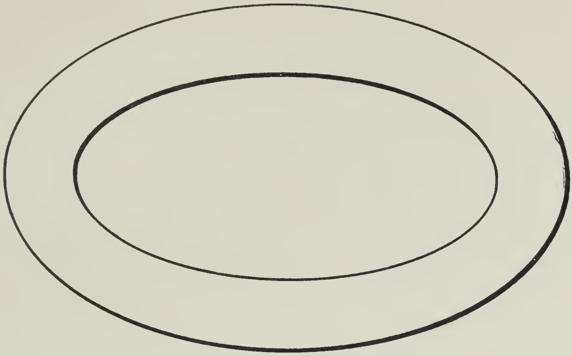

Fig. 32. (Full size.)

If the iron is too much reduced, or the weld bad, cut out the imperfect part, and repeat. This will, of course, make the link too small. Afterwards, take a new piece, and try again.

The scarfed surfaces in this exercise may be prepared in another way, using the face of the

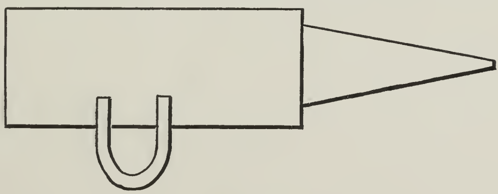

Fig. 33.

hammer instead of the pene. Having upset and bent the piece as before, lay it on the anvil as in Fig. 33, only about half an inch of the ends rest-

ing on the anvil. With a full red heat, strike a blow or two on one end, holding the face of the hammer parallel to that of the anvil. Draw the piece toward you about $\frac{1}{16}''$ and strike again. Repeat this operation out to the end of the piece, then turn it over and treat the other end the same way. The edge of the anvil thus serves the same purpose as the pene of the hammer in the previous method. In this case also, as before, the piece must be lightly hammered on the sides to partially correct the spreading.

LESSON VIII.

BLACKSMITH AND HELPER.

You will now join two separate pieces by a scarf-joint. In this case, both pieces, when prepared and heated, will have to be held in tongs to bring them together. If one workman attempts to do this, he has to lay down one pair of tongs and take up his hammer, and thus runs the risk of having one piece fall out of its place, or both pieces get chilled. The operation is therefore much more easily performed with the aid of a "helper," who follows the lead of the other workman, called the "blacksmith" or "fireman," striking and stopping as the latter directs, and working the bellows while the other manages the fire. A skilful workman can indeed perform this task without a helper, particularly with the aid of certain devices to be described presently; but many other operations, particularly on heavy pieces, are impossible without a helper.

Cut two pieces of 1″ square iron, each 5″ long. If you fail to do this exactly, make a memorandum of the exact amount of your error, that you may, when the work is finished, learn how much has been used up in the weld, and therefore be

able to make the proper allowance for such a joint in the future.

Exercise 16. Use of fuller.

Place both pieces with one end in the fire, but bring only one at a time to a white heat. Having the services of a helper, we will this time prepare the scarf with the tool called a "top-fuller." This is a tool very much like the pene of your hammer, the edge being set (as may also be the case with the hammer) either parallel or perpendicular to the handle. It is held in one hand by the blacksmith, and struck with a heavy hammer, or "sledge," by the helper, while it rests on the part of the piece which is to be indented. As an unskilful blow may give a painful jar to the hand of the holder, the handle of this or any similar tool is sometimes made of twisted wire, or even of a withe or rod of hazel or other flexible wood. The rod is several times wetted, heated, and twisted at the middle, to loosen the fibres of which it is composed. It is then passed once or twice round the head of the tool, twisted, and held in place by a small iron ring, as in Fig. 34. With this flexible handle the hand of the holder is safe from shocks. A similar tool, with the edge turned upward and shaped like the hardee, so as to be set in the anvil, is called a "bottom-fuller."

To make the scarf-joint with this tool, the fireman brings the end of the piece to a white heat,

as before, and bevels and upsets it, as in Figs. 24 and 26. Then, taking the fuller in the right

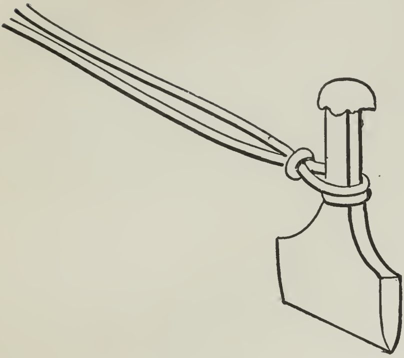

FIG. 34.

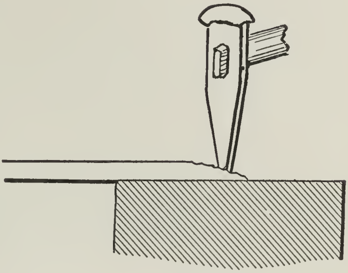

FIG. 35.

hand, he holds it on the bevelled surface, as in Fig. 35, while the helper strikes it with the sledge. It is easy to see that this tool can be guided with more accuracy than the pene of the hammer. With this the two pieces are brought to the form shown in Fig. 31 B. They are then laid in the fire, the scarfed surfaces downward, that no dirt may fall on them as they are removed from the fire, and as close together as they can be placed without touching, in order that they may arrive at the welding heat at the same time. They must not touch, however, as they would adhere in the fire. When they have been sprinkled with sand and brought to the full welding heat, they are taken quickly from the fire, first one piece by the helper and then the other by the blacksmith. The helper

Exercise 17. Scarf-joint with two pieces.

goes first, because his place is on the farther side of the anvil, while the blacksmith stands between the anvil and the fire. The helper strikes with his piece a sharp blow on the edge of the anvil farthest from him, to knock off any cinders that may be on it, and then rests it on the near edge, as in Fig. 36, the scarf surface up, but being very

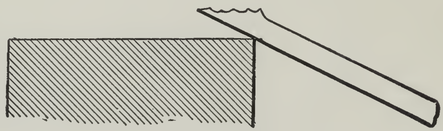

Fig. 36.

careful not to let the thin edge of the iron touch the anvil, which would chill it. The blacksmith follows quickly with his piece, knocking off dirt in the same way, and places it on the first piece, as in Fig. 37. It is of the utmost importance that

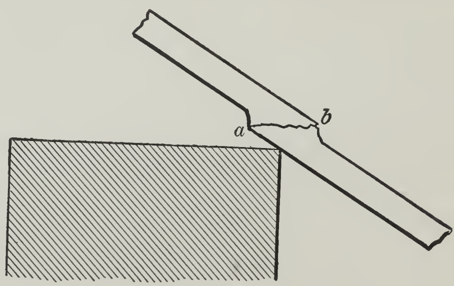

Fig. 37.

the first piece be neld quite steady, and the second placed on it in exactly the right position. If it laps a little too much or not quite enough, the scarf will turn out bad. The thin edges, which

may have cooled a little in the air, are heated again by contact with the thicker parts. A quick light blow or two at *b* by the blacksmith, will make the iron adhere. The blacksmith turns the piece over and makes it adhere at *a* in the same way. It is then laid flat on the anvil, as in Fig. 38, and welded,

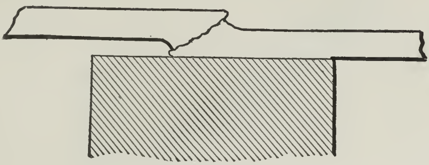

FIG. 38.

with heavier blows, by blacksmith and helper together, the former with his hammer, the latter with a sledge. The blacksmith strikes wherever he considers it best, and turns the piece when necessary, and the helper follows him, striking at the same point, and beginning and stopping when the blow of the blacksmith's hammer on the piece or on the anvil gives the signal. Test the weld before finishing. Holding one end of the piece with the tongs, strike it at the middle, while hot, over the horn of the anvil, bending it, and then again straightening it or bending it the opposite way. The weld should not open under such treatment. If the weld is satisfactory, the piece is finished smooth and square with the "flatter," Fig. 39, which is held on the bar by the blacksmith and struck by the helper. With this tool, of course,

a better finish is possible than with the hammer alone. The bar should be tested at the weld with calipers and square, and made perfectly straight. After this it may be finished smooth and partially polished, by dipping the face of the flatter in water

Exercise 18. Use of the flatter.

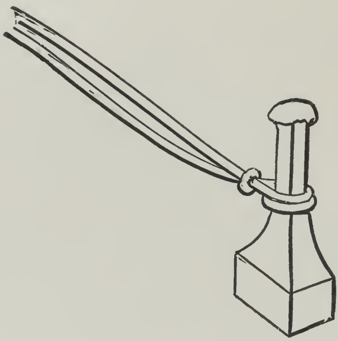

FIG. 39.

and slightly wetting with it the face of the anvil during the last part of the hammering.

The result of the work should be—

1°. A perfectly straight bar;
2°. Of uniform cross-section of 1″;
3°. Perfectly square;
4°. Without any twist;
5°. With no visible or a scarcely visible weld;
6°. Nowhere burnt;
7°. Quite smooth and polished; and,
8°. Exactly 11″ long.

If its length differs from that given, it is be-

cause you did not cut the pieces to the right length, or because you have used up too much material in welding. In either case note the facts in your memoranda, and be forewarned for the next task of the kind.

LESSON IX.

WELDING (CONTINUED). A TONGUE-WELD.

The scarf-weld just practised is an excellent joint, and, for most purposes, as good as can be desired. For many heavy pieces, such as shafts of steamers, the tongue-joint, Fig. 40, is often

Fig. 40.

used, and even in smaller work, such as the repairing of a broken wagon-axle, it is useful. Moreover, it can be more easily managed without the aid of a helper than the scarf-joint can. We will exemplify it with pieces of the same size as those used in the last exercise. Cut them, as before, to the exact length, or record the error.

Heat the pieces, and hammer one of them out on the edge of the anvil, to the wedge-form, Fig. 41, A. The hammering will "spread" or widen the piece on the edge, as shown in the plan B. This widening is to be, for the present, only very slightly reduced, by hammering on the sides.

Upset the other piece as in the last exercise,

giving it the appearance shown in Fig. 42, A. This piece is now to be split and opened, as

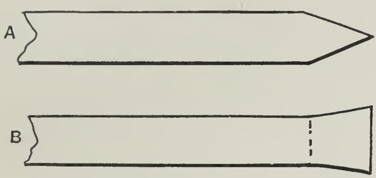

FIG. 41.

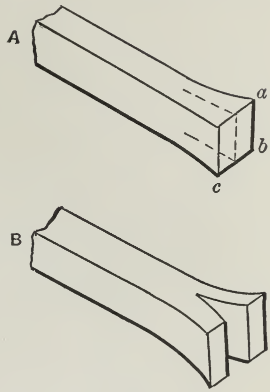

FIG. 42.

shown in Fig. 42, B, to a depth equal to the length of the wedge. It is important that the opening should be of this depth, otherwise a

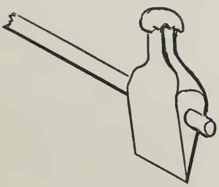

FIG. 43.

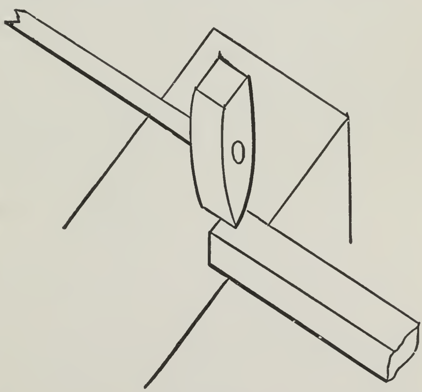

FIG. 44.

portion of the reduced thickness of the wedge will be left exposed, and the piece, when finished,

will be too small at this point. If, on the other hand, the cut is too deep, the wedge will go in too far, and the piece will be shortened, besides being thickened at the joint. The slit is made with a "hot chisel," Fig. 43, that is, a chisel adapted to the cutting of hot iron. While the piece is at a bright red or white heat, the blacksmith holds it on the edge of the anvil, as in Fig. 44, and holds the chisel on the line of the proposed cut, and the helper drives the chisel in with blows of the sledge. The workman does not try to make the whole length of the cut at once, but begins at the end, and works gradually inward. When the cut is about half-way through, he turns the piece over

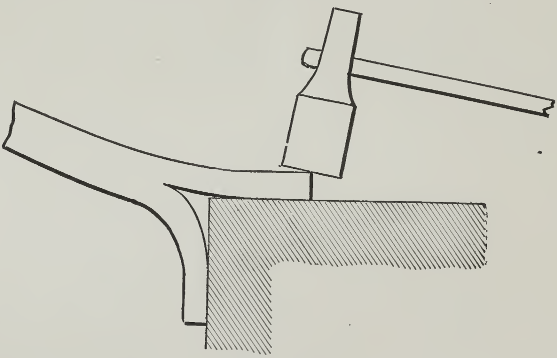

FIG. 45.

Exercise 19. A split or V-weld.

and works from the other side. The cut being made, it may be widened by setting the piece on end, with the cleft up, and driving the chisel into it, or by setting it up with the cleft down, and driving it

on the hardee, or on a bottom-fuller. When the piece has been split, hammer out the edges of the jaws a little, as in Fig. 45, thinning them only a little, and then close the jaws again, partly, as in Fig. 46. If you have no helper, the whole opera-

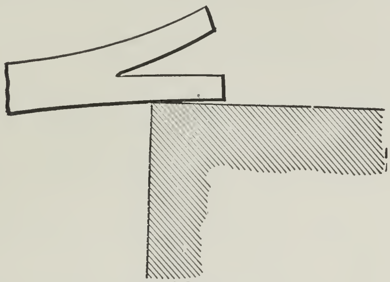

Fig. 46.

tion may be performed, though not quite so easily, on the hardee and a bottom-fuller, or even by holding the piece in the vise, and splitting it with a chisel.

The split piece, or V-piece, being now again heated to whiteness, the blacksmith holds it upright on the anvil with one pair of tongs, and the cold wedge-piece with another pair, while the helper drives it in gently. The wedge must enter to its full depth, and, if necessary, the cut must be extended for this purpose, for the reason already given. It must also go quite to the bottom of the cut, otherwise a hole will be left in the finished piece at that point.

The wedge being quickly driven in to its proper

depth, the pieces are turned over on their side, and the jaws of the slit hammered down closely on the wedge, the blacksmith and helper pushing the pieces firmly together all the time, to prevent the wedge from slipping out. The ears *a* and *b*, Fig. 47, B, which project beyond the edges

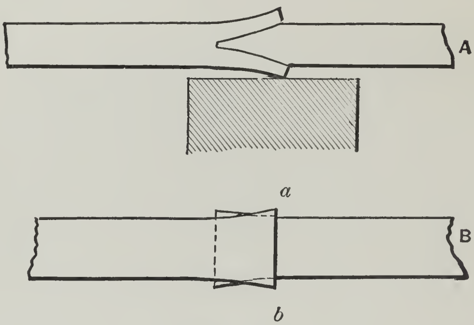

FIG. 47.

of the wedge-piece, are to be turned down round it, thus holding the two pieces together while the weld is being finished. The two pieces thus joined together are laid in the fire and brought to a welding heat. Two or three blows struck lengthways will make the weld secure at the middle. Then reheat, and, blacksmith and helper together pushing strongly towards each other, finish the weld while the piece lies on its side and is turned to and fro by the former.

The finishing is effected in the same way as in the last exercise, and the same tests are applied to the work.

This joint can be made by one workman alone, if he is skilful and the pieces are not too large. He will cut the slit on the hardee, or in the vise with a chisel. To drive the cold wedge into the V, he will hold the V-piece, red-hot, upright in the vise, and holding the cold wedge-piece in the hand, drive it in with the hammer. He will then squeeze the jaws of the V together with the tongs, and turn the ears over the wedge by light blows of the hammer on the anvil. The two pieces should then hold together firmly enough to allow of handling them (with care) in the fire, while being heated for the weld.

The V-weld, or split-weld, is especially valuable for very large pieces. With such pieces, after the joint has been formed and the two pieces have been fitted together, and while they are at a welding heat in the fire, they are partly welded, without removing them from the fire, by blows of a heavy sledge on the end. Only the finishing of the weld has then to be done on the anvil.

LESSON X.

TESTING IRON. MANUFACTURE OF CAST-IRON.

Bars welded by any of these methods should be almost as strong as bars without welds. They can be readily tested in a machine such as that used in the Lessons on Wood-working, only larger and stronger. Such machines are made of sufficient power to break a bar of wrought-iron five inches in diameter. The small machine will serve for testing wires, and such pieces as were used in your first exercises; and you should now make a few welds with such iron and test them, comparing their strength with that of the solid bar.

Exercise 20. Testing bars and welds.

Put one of these pieces, $\frac{1}{4}''$ square, into the machine, and apply a gradually increasing force till the piece breaks. The cross-section being $\frac{1}{16}$ of a square inch, the "tensile strength" or "tenacity" of the iron per square inch is sixteen times the amount that the testing-machine indicates. If the bar were round and $\frac{1}{4}''$ in diameter its cross-section would be about $\frac{1}{20}''$ ($\frac{314}{6400}''$), and the tenacity about 20 times that of the specimen. This strength varies,

for different kinds of wrought-iron, from 35,000 to 55,000 lbs. It is usually higher for iron wire than for bar-iron, because none but the best quality of iron can be used for making wire, and besides, the "drawing" of the wire lengthens and compresses the fibres, thus giving additional strength. Test two or three specimens of wire, and calculate their tensile strength.

The tensile strength of wrought-iron is not the only important quality that can be tried and measured in the testing-machine. Good wrought-iron should have great ductility, that is, it should suffer considerable stretching, and consequently considerable reduction of cross-section, before breaking. If it does not, it is not fit for use in such a structure, for instance, as an iron bridge, because when a great stress is put upon it, instead of stretching, and so giving warning, it will break suddenly. It is usual, therefore, with engineers to require that the iron to be used in bridges, shall suffer an elongation of 12 to 20 per cent and a reduction of cross-section of 30 per cent before breaking. Measure the diameter of the section of the broken rod at the point of rupture, compute its area, and the percentage of reduction.

Exercise 21. Test of ductility.

Besides tenacity and ductility, good wrought-iron has great hardness and stiffness, that is, it requires great force to crush it or to bend it. Test

a specimen of $\frac{1}{4}''$ wrought-iron in these respects in the machine, and record the results for comparison hereafter with cast-iron and with steel. You will find that while different kinds of wrought-iron differ from each other, they are, on the average, superior in all these respects to cast-iron.

The differences between cast-iron, wrought-iron, and steel, and between different specimens of each, result from their composition and mode of manufacture. Cast-iron is a mixture of iron with about 4 to 7 per cent of carbon, which makes it fusible at about 1100° C. or about 2500° F. It generally contains also, small quantities of other substances, as sulphur, silicon, and phosphorus, which have various effects on its fusibility, its ductility, and its hardness. As more and more of the carbon is removed, the iron becomes first steel and then wrought-iron, endless varieties of each resulting from the kind and quantity of the impurities. The way in which these substances find their way into the product, and the means by which they are removed, will be understood from a brief description of the methods of manufacturing cast-iron, wrought-iron, and steel.

The broken-up ore is placed in a structure forty to eighty feet high, called a "blast-furnace," shown in Fig. 48, in layers alternating with layers of coal or charcoal and of broken limestone. The coal being ignited and a strong blast of air driven

through the iron pipes or "tuyeres" which enter the furnace near the bottom, the heat melts the material above, which flows off below through the opening shown in the figure. Fresh layers are added above, and thus the furnace is kept in constant action, for months or years, till it becomes necessary to let the fire out in order to make repairs.

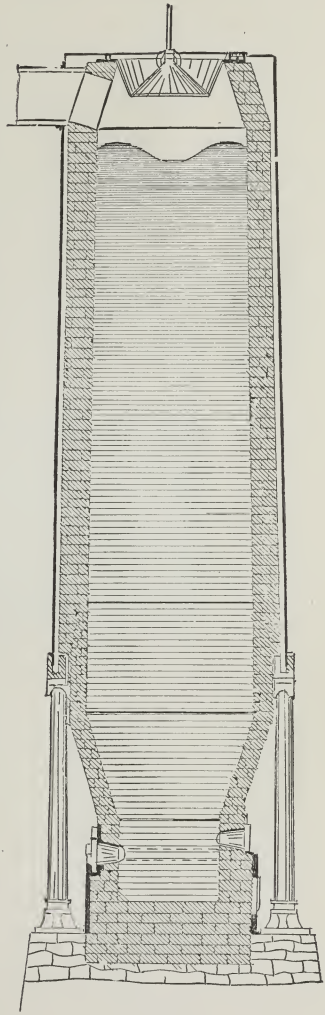

FIG. 48

The use of the coal in this operation is evident. That of the limestone is to form an easily fusible mixture with the silica or sand and the earthy matter of the ore, and cause it to flow off. At the same time some of the carbon of the fuel joins with the iron and makes another fusible mixture, cast-iron. There are thus two fluids constantly accumulating in the bottom of the furnace. The heavier one settles

to the bottom, and is drawn off from time to time, through an opening made for the purpose, as cast-iron. The lighter one floats above this, and is drawn off through another opening, as "slag" or "cinder." When cold, it is usually, though not always, broken up and thrown away as a waste product.

The iron thus obtained from the furnace flows down a trough *AA* in a bed of sand on the floor to the troughs *BB*, and thence into the moulds

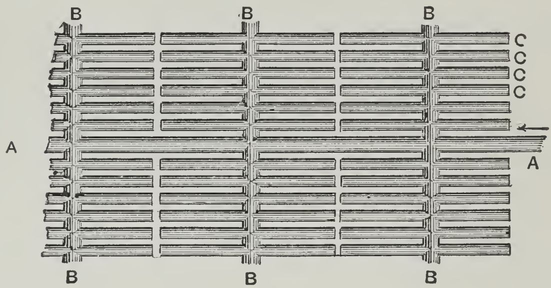

Fig. 49.

CC. One of the groups composed of *B* and *C* is called a "sow and pigs," and the pieces *C*, each of which is about three feet long and contains about 100 lbs. of iron, is called a "pig."

The "pig-iron" thus produced contains various impurities, according to the kinds of ore, lime, and fuel used. The study of the various grades of pig-iron would lead us farther than we can go at present. They are designated, in part, by the name of the country or district in which they are

produced, or the furnace producing them—Norway, Cumberland, Lowmoor, Warwick, Salisbury. Besides this, they are also divided into three principal grades used for different purposes. These are:

"No. 1," which is coarse-grained and very dark and soft, and is used for foundry-work;

"No. 2," which is less coarse, but still dark and soft, and is also used for foundry-work;

"No. 3," or Gray Forge, also sometimes called No. 1 Mill;

"*Mottled*," which is light gray with specks of white; and,

"*White*," which is white all over.

The last three are used for reheating and manufacturing into refined iron, as explained in Lesson XII.

LESSON XI.

FOUNDRY-WORK.

CAST-IRON is readily fusible, and a great many articles are made directly from it in the "iron-foundry," different kinds of pig being mixed together to obtain the desired quality. To illustrate the method of casting or founding in metal, which is the same in its essentials, whether the metal be iron, steel, brass, or zinc, we will cast a small object in brass, which can be melted in your forge-fire or in that of a small portable furnace, while iron would require a much higher temperature. We will take for the object the square prism shown in isometric projection in the sketch, Fig. 50, to be used in a later exercise. The rough casting must be a little larger than it is shown in the sketch, to allow for waste in finishing. The amount of the difference depends on the fineness of the casting. If the casting is very rough, $\frac{1}{8}''$ may be lost on each face;

Exercise 22. Making a pattern.

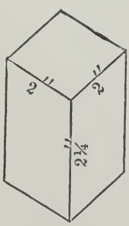

FIG. 50.

if very smooth, less than $\frac{1}{16}''$ may be enough. As we shall perform several operations on the casting before finishing it, we will make the casting $2\frac{1}{8}''$ square and $2\frac{1}{2}''$ long. If, however, we make a mould of this size, the metal when poured into it will shrink in cooling, and make the piece too small. It is usual, as the result of experience, to allow about 1 per cent or about $\frac{1}{8}''$ to a foot for shrinkage; but this allowance, which is important in large pieces, may be neglected in so small a work as the present.

If the pattern were made of the size and shape thus far determined on, you would find, on trying to perform the next operation, that you would fail. After packing the sand round your pattern in the mould, you would find that the pattern would not "draw," that is, it could not be lifted from the sand without breaking down the mould. It must be a little thinner on that side which is set deepest in the sand. The least taper that will suffice for this purpose is about $\frac{1}{8}''$ in a foot, or about $\frac{1}{100}''$ in an inch. Allowing something more than this in this very small piece, you may make one face of your pattern about $\frac{1}{40}''$ wider than the opposite face. Finish up the pattern as smooth as you can make it, and give it a smooth coat of shellac varnish.

The process of "moulding" consists in making a depression in sand, of the size and shape of the

pattern, and that of "casting" consists in filling this depression with the melted metal. The sand must be very firm, and just moist enough to "pack," or stick together slightly when squeezed in the hand. If it is moister than this, it may cause accidents by the sudden generation of steam when the melted metal is poured into the mould. The sand is held in place while it is being packed round the pattern, by a moulding-box or "flask," of wood or iron, formed in two parts, which can be separated and put together again in exactly the same position, being guided by two pins in one part, which pass through two holes in correspond-

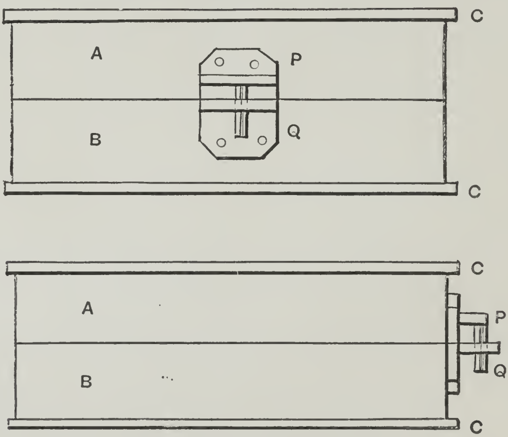

FIG. 51.

ing "lugs" on the other. Each part is accompanied by a flat "moulding-board" about two inches longer and wider than the flask, with "tongue-and-grooved" strips across the ends to

prevent it from warping. The two parts *A* and *B*, with the moulding-boards *C*, are shown in front elevation and side elevation in Fig. 51, where *P* and *Q* are the upper and lower lugs.

Exercise 23. Moulding.

Set one half of the flask on its moulding-board, with the lugs downward. Sprinkle some fine sand on the lower part of the flask, through a sieve, and fill up the remainder of the box without sifting, but press and ram the sand firmly into the corners of the box till it is quite full. Scrape off the excess with a straight-edge, sprinkle a little loose sand on the surface, and cover it with another board, rubbing this to and fro till it fits closely on the edges of the box. Now, grasping the edges of both boards in the hands, turn the box over without disturbing the sand, and remove the upper board. Sprinkle the moist surface of the sand with fine red brick-dust obtained by crushing bricks. Put the dust into a linen bag, and sift it out by shaking the bag while holding one corner of the open end in one hand and a corner of the bottom in the other. Blow off any excess of dust, and lay the pattern on the sand with the wider face down. Sprinkle the surface of the pattern with dust, then set the upper part of the flask in place, and fill it, and cover it with a board in the same way as the first.

The upper half is now to be removed, so that

the pattern may be taken out. Tap the top board gently all over with a light mallet. This will loosen the sand a little from the pattern, and the brick-dust will prevent the two surfaces of the sand from sticking together. Taking hold of the upper box and moulding-board with both hands and lifting carefully straight upwards, you can remove this box and turn it over on its moulding-board. In lifting, you must be careful to keep the box quite level and not to move it horizontally, or you will break the mould.

If the sand has not broken away to any considerable extent, you may remove the pattern; but if it has, the breaks must first be repaired. Moisten a little the hollows from which the sand has been torn out, and replace the other box. The pieces torn out will adhere and remain in their proper places, where they can afterwards be smoothed off, if necessary, with a small trowel. If the pattern should happen to come off with the upper flask, it can be removed by sticking into it, obliquely, two sharp-pointed steel wires, tapping them gently sideways and endways to loosen the pattern, and then lifting it out by the wires as handles.

In one end of the flask there is a hole through which the melted metal is to be poured in. Connect this with the end of the mould by a small channel cut with the trowel, and smoothed and

hardened at the entrance by the pressure of the finger. Repair any small breaks, blow out any loose sand, dust both surfaces of the mould lightly with flour or with finely powdered charcoal in the same way that you applied the brick-dust, put the two halves of the flask together and clamp them in place, and everything is then ready for the pouring of the metal.

Brass is best melted in a brass-founder's furnace, which, however, it is not necessary to describe here, as the small quantity required at present can be melted in a crucible in your forge. Make a fire of good hard coke, in pieces about two or three inches in diameter. Set the crucible on this, mouth downwards, urging the fire gently till it is thoroughly heated, because, if heated first on the outside, or too suddenly, it is apt to crack. When it is red hot all over, turn it over, build up the fire round it to the edge, put in the charge of metal, and cover it with large pieces of coke. The amount of metal required can be determined approximately from the fact that the density of the metal is 14 or 15 times that of the wooden pattern. To allow for waste, however, and to be quite sure of having enough to fill the mould, let the weight of the charge be from 20 to 25 times that of the pattern. Keep up a strong draught with the bellows, till the whole of the charge is melted.

Brass is an alloy or mixture of copper and zinc, usually in the ratio of 90 to 10. When it is ex-exposed to the air at a very high temperature, the zinc burns, giving off a light blue flame and a cloud of white smoke. For thin castings, which chill quickly, and which therefore require a high temperature, the metal should be poured in this condition. For such a piece as the one in this exercise, a somewhat lower temperature will be best, such as is unattended by the flame and smoke. When the metal has cooled to this point, skim off the dross, and it is then ready to be poured.

Exercise 24. Casting brass.

For this purpose, after having turned the flask downward to let any loose sand that might possibly have fallen into the mould fall out, set it upright, with the mouth up, and in such a way that the point of the mould at which the inlet enters shall be the highest point, otherwise the air will collect at any point that may be higher, and prevent the metal from entering. Pour the metal carefully into the mould, in a steady stream of such size as to leave room in the channel or "ingate" for the escape of the air without forming bubbles, which might scatter the metal. The mould must be filled quite up to the ingate, to insure soundness of the casting at the top. When the casting is "set," the mould is opened, the piece cooled, the ingate-piece sawn off, and the ridge along the line of meeting of the halves of the flask filed away.

LESSON XII.

MANUFACTURE AND PROPERTIES OF WROUGHT-IRON.

WE have seen that the two kinds of iron, called No. 1 and No. 2 foundry pig, are used singly or mixed in various proportions for cast-iron, and No. 3, or forge-pig, is manufactured into wrought-iron. The manufacture consists in expelling the other substances, mainly carbon, silicon, phosphorus, and sulphur, with which it is mixed, leaving pure iron.

For this purpose, the iron is again melted in a furnace without blast, called a "puddling-furnace," where it is stirred up with wrought-iron rods till nearly all the carbon has been burned out of it by contact with the air, and the other impurities have been carried away in a "slag," made by throwing limestone, oxide of iron, salt, and other fusible substances into the furnace. It thus becomes first pasty and then granular, and requires a very intense heat to keep it from solidifying. In this state it is taken out of the furnace in lumps of about 40 lbs., on the ends of the iron rods, and hammered by heavy hammers driven by machinery, or compressed between powerful "squeezers," the remaining silicon and other im-

purities being thus pressed out. The lump of pure iron thus obtained is passed between strong cylindrical rollers, which have grooves turned in

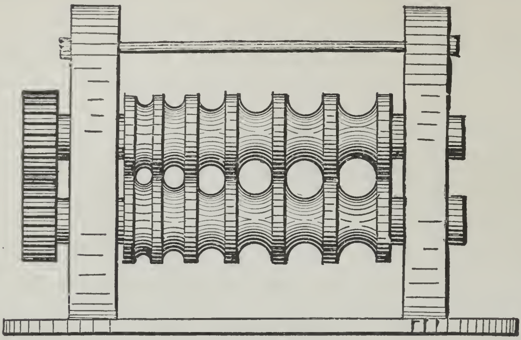

Fig. 52, A.

both, opposite each other as in Fig. 52, and thus drawn out into bars from 3 to 5 inches wide, and

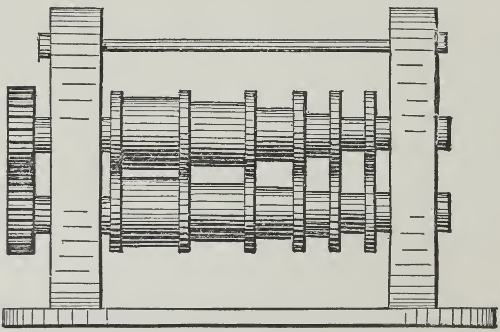

Fig. 52, B.

from $\frac{5}{8}''$ to $\frac{3}{4}''$ thick. These are called "muck-bars," or "puddled bars," and are coarse wrought-iron. These bars are cut into short pieces, which are fastened together, reheated, and again rolled out to such sizes and shapes as may be required.

The iron thus produced is called "refined" iron. This iron is sometimes again "piled" and reheated and rolled, producing what is called "double refined" iron. After these operations the iron will be found to have an entirely different structure from that of cast-iron. The latter is composed of granules or crystals. Wrought-iron, if good, has lost its granular or crystalline structure, each of the granules having been drawn out into a long fibre, so that the bar itself is a bundle of such fibres stuck together at their sides. Wrought-iron thus resembles a piece of tough wood, while cast-iron is more like unstratified stone, such as granite. Cast-iron has the same structure and strength in all directions, while wrought-iron is tougher or harder to tear asunder by a force applied in the direction of the length of the fibres than by one applied perpendicular to this direction,—in which respect again it is analogous to wood. (Wood-working, p. 17.)

This fibrous structure is possessed in very different degrees by different kinds of wrought-iron. An iron of poor quality can be readily broken across by bending. Take a piece of $\frac{1}{2}''$ bar-iron of the cheaper (and therefore poorer) quality. Nick it on one side on the hardee. Lay it across two pieces of $\frac{1}{2}''$ flat iron three or four inches apart on the anvil, the nick being between the supports, but

Exercise 25. Testing wrought-iron on the anvil.

near one of them, and strike it a heavy blow or two with the pene of a hammer. If the specimen is of very poor quality, or "cold short," it will break at the nick. A piece of better quality will stand bending cold at right angles without breaking; and a very tough piece may be bent double without breaking, or will split at the nick, as in Fig. 53. The best bar-iron can be tied in a knot cold, though not after it has been nicked.

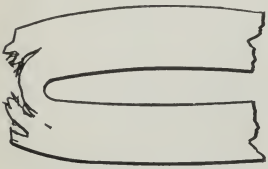

Fig. 53.

Break in this way two or three pieces of iron of different qualities. Examine the surfaces of the fractures with a lens. You find that the better or tougher the iron, the more distinctly fibrous it is; and you can soon learn to judge of the quality of wrought-iron, as of cast-iron, by the appearance of a freshly-broken surface.

LESSON XIII.

MANUFACTURE AND PROPERTIES OF STEEL.

You have learned that wrought-iron is nearly or quite pure iron, while cast-iron contains from 3 to 5, or, in some cases, even 7 or 8 per cent of carbon. Steel is intermediate in composition between these two, and contains from 1 per cent to 0.15 of one per cent of carbon. It might be supposed, therefore, that steel could be made in the puddling-furnace by stopping the operation before the carbon is all removed; and this process is sometimes actually used. It is difficult, however, to obtain in this way a product containing exactly any desired proportion of carbon, and besides, the distribution of the carbon throughout the mass is apt to be irregular, or, in other words, the steel is not homogeneous.

For a long while, therefore, steel was made almost exclusively from the best qualities of wrought-iron by a process called "cementation," a process which is still in use for the manufacture of fine steel. The bars of wrought-iron are em-

bedded in powdered charcoal, and baked in a furnace for from seven to fourteen days continuously. The iron is then found to have increased in weight about 1½ per cent by the absorption of carbon, and has become what is called "blistered" steel, from the blisters which appear on its surface, and which are probably caused by the escape of bubbles of air.

From the blistered steel two other kinds are made called "shear" steel, and "cast" or "crucible" steel. The former is made by fastening together a number of bars of blistered steel, and hammering them at a welding heat with a trip-hammer. The process is like that of refining wrought-iron, and has a similar effect—the production of a more or less fibrous structure. The steel thus made is especially adapted for welding to wrought-iron, and is commonly used in making the cutting edges of those tools of which the other parts are made of iron. The other kind of steel is made by melting in crucibles bars of blistered steel, broken for the purpose into convenient fragments. This is harder to weld than shear-steel, and is used principally for objects which are entirely of steel, and which are cast in the shape required, although it can also be welded, with proper precautions.

As long as steel was manufactured only by the methods just described, only a small quantity

could be produced at once, and it was therefore very expensive. When large works are to be made of crucible steel, it is necessary to have great numbers of crucibles ready at the same time for pouring, and very great care is necessary to make sure that the charges of all the crucibles shall have exactly the same qualities. With such precautions, however, very large works, such even as cannons weighing 139 tons, are satisfactorily cast at the great Krupp foundry in Germany.

In recent times much less expensive processes have been devised for making steel in very large quantities. These are known as the Bessemer process and the Siemens-Martin process. They need not be described at present. They are used mainly in the production of very large pieces, such as are used in the construction of heavy machinery, bridges, railroad tracks, steel ships and cannon, and the armor-plating of war-vessels. For small tools, shear-steel and crucible-steel are still generally employed.

To the mechanic who is working in steel, the properties of the metal are generally more important than the way in which it may have been manufactured ; and in whatever way his steel may have been made, he distinguishes what he calls "high-grade" or "tool" steel from "low-grade," "mild," or "machinery" steel. The former con-

tains about 1 per cent of carbon, the latter from $\frac{1}{5}$ to $\frac{1}{7}$ as much.

Exercise 26. Testing steel on the anvil.

On your anvil are two specimens of $\frac{1}{2}''$ square steel, each 18″ long. One is of high grade, the other of mild steel. Study the properties of each. First, heating them to redness, nick them both on the hardee, 8″ from the end; and then, after cooling them slowly, try to break them as you did the iron in Exercise 26. Or better, lay the piece across the hole in your anvil, hold a narrow fuller on the nick, and let a helper strike with a sledge till the piece breaks. Compare the effort necessary to break each of these with that required to break a piece of bar-iron similarly treated. Examine the fractures and compare them with each other, and with that of good wrought-iron. Make memoranda of the results of all your observations.

Next, wedge the short pieces one after the other in the hole of the anvil, making, if necessary, a wrought-iron wedge to hold the piece tightly in position, about 2″ of the piece being in the hole. Strike the piece sideways near the upper end, till it is bent aside at an angle of 50° or 60°. Strike it on the other side and bend it back to an equal extent in the other direction. Try to break it by repeated bendings, and note how much of such treatment each piece will stand. Cut a simi-

lar piece of bar-iron, and compare this with the two kinds of steel.

Next, heat one end of each piece to a cherry-red, plunge it quickly into water, and hold it there till cold. With an old file try the hardness of the end thus treated, and compare with that of the opposite ends. You find that sudden cooling from a red heat hardens tool-steel. You have long ago found that no such effect is produced on wrought-iron; and you find that mild steel is in this respect much like wrought-iron.

Exercise 27. Experiments in hardening.

Again, test the piece thus hardened for toughness, as you did before hardening it: you find it has become not only hard, but brittle.

Lastly, heat about 2″ of one end of the tool-steel to whiteness, and treat it as you did wrought-iron, in previous exercises for drawing and pointing. You find it brittle, like hot-short iron, and it is evident that it cannot be worked at such a heat. Try successively lower temperatures, till you find one at which it can be forged. Do the same with the low steel. You will find hereafter that though the steel is not made brittle at this temperature, it has probably suffered another injury, which you will understand when you come to consider the subject of "hardening" and "tempering" steel, that it is necessary to work it at a still lower temperature, and that each kind of steel has a temperature of its own at which it

can be worked, and which, generally, can be ascertained only by trial.

Collect, now, all the points of resemblance and of difference that you have discovered between wrought-iron, cast-iron, mild steel, and high-grade steel, and write them out in a clear and orderly manner in your memorandum-book.

LESSON XIV.

WELDING STEEL: LOW GRADE.

We will make our first attempt at a steel weld with a low-grade steel containing about $\frac{1}{7}$ of 1 per cent of carbon. This may be either a mild shear-steel, or a Bessemer steel of about the quality now used for carriage-tires. It will differ but little from wrought-iron, except that it will be tougher. It will be easier to weld than tool-steel, but will require more care than wrought-iron. We will take the tough 6″ piece of the last exercise, and join it again to the piece from which it was cut.

First, straighten the pieces at a dull-red heat. Upset and scarf one end of each piece, with the aid of a helper, using a fuller, and proceeding as in Exercise 19. Be careful to use a coke fire instead of one of green coal, and to work at a low heat, never exceeding a cherry-red. Unless you work very expeditiously, therefore, striking always at exactly the right place, and without loss of time, you will not be able to prepare the scarf-piece in one heat. Reheat cautiously, moving and turning the piece occasionally in the fire, and watching the color closely. Keep the other piece in the edge of the fire, so that it shall be nearly ready

Exercise 28. Welding steel on steel: low grade.

for use when wanted, but in no danger of burning. Make the scarf in as few heats as possible. When the two surfaces are prepared, put the pieces in the fire side by side, as in Exercise 19, and raise them slowly to a cherry-red. Sprinkle the scarf-surfaces with powdered borax and allow it to melt, and spread over the surface before you put the pieces into the fire again. Heat them slowly, and as soon as the borax smokes, which will be an indication that they have reached a cherry-red, withdraw them from the fire, and finish the weld as in Exercise 19, observing all the precautions there described, but remembering that, after the first adhesion of the two surfaces, there is not the same necessity for rapid work in this case as in the iron weld, because the steel, being worked at a lower temperature, does not quite so quickly fall below the required heat. Remember that, in this case as in the previous ones, it is essential to a good weld that you should have a bright, clean, and deep fire; but you should not have a broad one, as that will heat too much of the length of the pieces. Finish square, straight, and smooth, as in similar work with wrought-iron, and test in the same way. If the result is not satisfactory, cut out the weld on the hardee at a red heat, and repeat.

Try next a split weld, of steel on iron, taking one end of the piece just finished, and an 8″ piece

of 1″ square bar-iron. Make this weld without a helper. Upset and split the iron, and lay it in the edge of the fire to keep it at a red heat while you are preparing the steel wedge-piece. This is because the steel must be worked at a lower temperature than the iron, and therefore, when they are presently put into the fire together, the iron should be hot and the steel cold, so that they may reach their proper heats at the same time. Hammer the steel to the wedge-shape, and fit the hot V-piece to it as in Exercise 19. Then, without letting the V-piece cool, place both together in a good welding fire and raise the steel to a bright cherry-heat, when the iron will probably be at a welding heat. During this operation keep them on the top of the fire, so that they can be easily watched, and move them about so that they shall not get too hot beyond the joint. In doing this, take hold of both pieces, and keep the wedge pressed well up into the split. When the joint is at the proper heat, take up some powdered borax on a bit of hoop-iron or small flattened bar-iron as a sort of spoon, and sprinkle it abundantly on the joint. Watch the melting of this, while you keep up the heat by means of the blast. When it has thoroughly run into and around the joint, and the steel is at a bright cherry-red, take hold of the joint with a pair of tongs while it lies in the fire,

Exercise 29. Welding mild steel on iron.

and without removing it, squeeze it vigorously. This will partially weld the joint, and enable you to handle the pieces with less risk of separating them. Remove them to the anvil, strike a few quick blows to make good the weld, and you can then finish more at your leisure, reheating the pieces as often as may be necessary. The finishing and testing should be exactly as in Ex. 19.

LESSON XV.

WELDING STEEL: HIGH-GRADE.

Exercise 30. Welding high-grade steel on steel.

We will now try a weld of high-grade or tool steel, which will be somewhat more difficult to manage. Take the piece of ½″ tool steel of Ex. 26. Be careful to perform all operations on it at a temperature lower than that at which you have found that it becomes brittle. Upset it as in the last exercise, holding the piece this time in the vise for the purpose. In upsetting in the vise it is easier to prevent bending, if you are careful not to strike too hard. On the other hand, if you set the piece too low in the vise you will limit the upsetting to the extreme end, and the work will turn out too thin when the weld is finished. While upsetting, keep the piece square and straight by occasional hammering on the anvil. With this kind of steel you will probably have to reheat each piece several times for each operation, which will do no harm unless you make it too hot. When it is properly upset, split it, again at a red

heat, holding it upright in the vise and using a thin hot-chisel. When the cut has been made to the proper depth, widen it a little with a duller chisel, spread the lips, form the wedge-piece, and drive it in till it reaches quite to the bottom of the cut, all as in previous exercises of the same kind. Put the pieces together and fit them as closely as you can, at a red heat. They are now to be heated together in the fire, with even more caution than in the last exercise as to the character of the fire, the moving about in the fire to heat all parts of the joint but without parting the pieces, and the keeping within proper limits of temperature. Sprinkle abundantly with borax without removing from the fire, pinch together in the fire, and weld and finish, all as in the last exercise.

This will probably be found to be a rather difficult task, and you may have to try several times before succeeding. Some of the causes of failure are the following:

1°. Overheating at any stage of the operation, which will cause the steel to break or crumble under the hammer.

2°. Underheating at the time of welding, which will prevent the pieces from uniting.

3°. Dirty fire, letting cinders get into the joint.

4°. Too much thinning of the lips of the V-piece, which will make the joint so weak that it

may be impossible to keep the two pieces together in the fire, or while removing them to the anvil.

5°. Too short a notch, leaving part of the thinned wedge exposed.

6°. Loss of time in striking, after removing the work from the fire.

7°. Imperfect contact of the edge of the wedge with the bottom of the notch, leaving a hole, or, if this is closed by hammering, leaving the piece too thin.

8°. Imperfect union of the edges of the lips of the V-piece with the sides of the wedge, owing to burning of the edges, which often happens if they are too thin.

LESSON XVI.

HARDENING AND TEMPERING STEEL.

You have learned (Lesson XIII., p. 79) that high-grade steel, when cooled from a red heat by plunging into water, becomes very hard. The same effect, with some differences in degree which need not be considered yet, results when the steel is cooled suddenly from the same temperature in any other way, as by plunging into oil or tallow, or even, if it is a thin piece, by contact with a large mass of cold metal, such as the anvil. Again, you have found that the piece which has been thus hardened has also been made brittle. In some tools, as in those intended for cutting metals and stone, this property of hardness is of great value; but on the other hand, the brittleness which accompanies it may very much lessen this value. The sharp corner of a scrap of glass, for instance, is hard enough to scratch iron or steel; but the brittleness of glass makes it worthless as a material for cutting-tools, as its sharp edge is quickly broken off. The same is true of very hard steel. It is important, therefore, to understand exactly

the means by which this hardness is produced, and the means by which the brittleness can be diminished without sacrificing too much of the hardness.

In the first place, the amount of hardness produced by sudden cooling depends on the temperature from which the cooling takes place. Perform the following experiment to satisfy yourself of this. Take four pieces of high-grade octagon or round tool-steel, $\frac{1}{2}''$ or $\frac{3}{8}''$ in diameter and $2''$ long. Mark them, near one end, with file-scratches, so that you can identify them. Let them lie for five minutes, one in boiling water, one in boiling linseed-oil, one in red-hot melted lead, and one in the fire till it is as hot as it can be made without burning. (The oil may be boiled in a small iron ladle on a dull forge-fire with a very gentle blast, taking care not to let it boil over, and, if it takes fire, raising it from the fire and letting it cool a little, so that you can blow it out, but without removing it from the forge, for fear of accident. The lead may be melted in a similar ladle, or in the same one after the oil has been poured off and the remnant of it burned out. The lead must be red-hot.) The first of the four pieces will then be at a temperature of 212° F., the second at about 580°, the third at about 1500°, and the fourth at about 2500°. Picking up each piece with a small pair of tongs which have been standing in the fluid or the fire so that their jaws are at the same temper-

ature as the piece of steel and will not chill it, drop each into cold water.

Test them, as to hardness, in the following way: Clamp the piece in a hand-vise, as in Fig. 54, letting it project about $\frac{1}{2}''$ at the side of the vise. Fasten the hand-vise to a piece of wood four or five feet long and $3''$ wide, with a screw and washer, as in the same figure. Supporting one end of the strip on a bench or table, and preventing it from shifting by means of a nail passing through an auger-hole, let the

Exercise 31. Experiment on hardening steel.

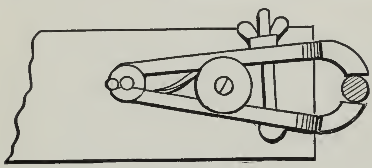

FIG. 54.

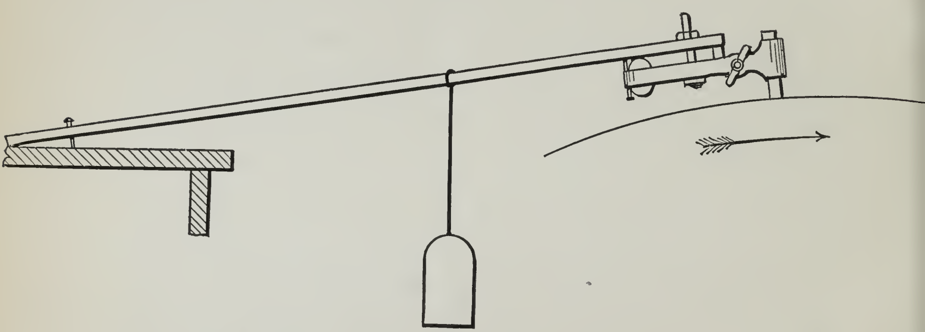

FIG. 55.

end of the piece of steel rest on the grindstone Hang a weight of 8 or 10 lbs. on the strip, to produce a suitable pressure on the stone, making a notch for the cord so that it shall be attached at the same place in all the experiments. Let the

piece bear on the stone, keeping it well watered, and grind the end square, moving it to and fro sideways, so as not to wear the stone in one place. When all the ends are square, weigh the pieces, and record the weight of each. Then grind off from each as much as the stone will remove in 1000 or 1500 revolutions, and weigh the pieces again. The percentage of loss of weight will indicate the softness of the pieces, since all have been treated alike. You can therefore arrange the pieces in the order of hardness, and can learn the effect of sudden cooling from these temperatures.

Next, holding the pieces in succession on the anvil, and striking them at the end with the hammer, first gently, and then more forcibly, you can learn, in a general way, which are the most brittle, though this experiment is only a rough one, and its results cannot be expressed in figures. Make a record of these results, and remember them.

The hardness produced by sudden cooling from a red heat can be entirely removed by cooling the metal slowly from a red heat; and the more slowly it is cooled, the softer and tougher will the steel be. The brittleness and the hardness are reduced together. Experiment on this in the following way: Heat three pieces of steel, such as you used in the last experiment, to a bright red

heat in melted lead, having, as before, marked them for identification. Harden them all alike, by plunging them suddenly into cold water. Then, heating them to a bright red again, cool them in the following ways:

Exercise 32. Experiment on annealing steel.

No. 1, by holding it in the tongs (previously heated to a "black red") and letting it cool in the air till the redness is invisible in the light, but just visible in a dark corner, and then plunging it into water.

No. 2, by laying it on the loose cinders in the forge, and letting it cool slowly in the air; and,

No. 3, by leaving it, red-hot (but not white-hot), in the fire, well covered with the coals and cinders, letting the fire go out, and leaving it there till quite cold.

Test these pieces for hardness and brittleness, as in the last experiment. You will find that the steel has recovered more or less of its toughness, and also of its softness, by this gradual cooling. This process is called annealing; and the three methods you have just tried are called water, air, and fire annealing. Make a record of the effects of each, and remember them.

It is usually said that while cooling suddenly from a red-heat hardens steel, cooling from a lower heat, whether slowly (as in the air) or quickly (as in No. 1 of your last experiments),

softens it. Try to ascertain from your experiments whether these statements are correct.

Glass is very much like steel in the effects of heat on it, while some metals and alloys, as copper and brass, behave, as you can now easily prove by experiment, in exactly the opposite way, being hardened by slow cooling and softened by rapid cooling.

You have found now that, in general, the harder steel is, the more brittle it is, and the tougher the softer. It is therefore impossible to retain the highest degree of hardness with great toughness; and for each particular use to which steel is to be put we have to try to secure the particular degree of hardness and toughness most nearly suited to that use.

As your experiments show that the hardness and toughness of steel depend on the temperature from which the metal is cooled, and as small differences in toughness may suffice to make a tool very valuable or altogether useless for a given purpose, it is important to know how to select the right temperature for each case. The red which is just visible in the dark (or black-red, as it is called) is a very good indication of one temperature—about 500° to 525° C., or 932° to 977° F.; but sudden cooling from this point gives a hardness which, though it serves very well for files, is too great for most other tools. If a tool which

has been thus hardened too much be raised again to some lower temperature, and then cooled from that temperature, it will be softer than before; and by selecting the proper temperature it will be possible to give it any lower degree of hardness that may be required. This process is called "letting down" or "tempering." Success in tempering depends—

First, on the selection of the proper temperature;

Second, on the method of applying the heat; and,

Third, on the method of cooling.

We will consider these three subjects separately:

1. The temperature used, when it is lower than the black-red heat, is indicated by the color which is assumed by a brightened portion of the surface of the steel. Iron or steel when heated in the air oxidizes on the surface. Grind two or three inches of the surface of an old flat file, making it bright on one side. Heat a piece of 1″ bar-iron, 15″ or 20″ long, to a bright red at one end, and lay the piece of brightened steel on it, in a good light, with the bright part projecting about an inch or two beyond the end of the hot bar. The projecting part will be cooler than the rest, and the heat will travel along to it gradually. Fix your atten-

Exercise 33. Experiment on colors of heated steel.

tion on the end, and watch and record the several colors as they appear there, one after the other. These colors are produced in the same way as the colors of the soap-bubble, and, like them, they change with the thickness of the very thin film which causes them. As the temperature of the steel rises the thickness of the film of oxide of iron increases, and the color changes. The color is therefore an indication of the thickness of the film, and that in its turn shows the temperature of the metal. It has been found that the temperatures corresponding to the several colors are as follows:*

1. Very pale yellow, . . .	221° C.	or	430° F.
2. Pale straw, ...	232	"	450
3. Full yellow, ...	243	"	470
4. Brown, ...	254	"	490
5. Brown, with purple spots,	265	"	510
6. Purple, ...	277	"	530
7. Bright blue, ...	288	"	550
8. Full blue, ...	293	"	560
9. Dark blue, ...	316	"	600

If a piece of steel which has been hardened be heated to one of these colors and then cooled, it will be softened, and the higher the temperature to which it has been raised the softer it will be. Try this in the following way: Take three pieces

* Percy's Metallurgy.

of octagon steel, as in your last experiments, and harden them by plunging them in water at a red heat. Rub them on a piece of grindstone or other sandstone to brighten them. Lay them on a red-hot bar of iron supported over a vessel of water. When any one of the pieces shows a pale-straw color, push it off into the water. Do the same with the others when they reach a light purple and a dark blue respectively. Now, using an old file, try how much of each piece you can remove by a given number, say fifty, of similar strokes of the file, and thus compare the results obtained by tempering from these various temperatures. You might measure the hardness on the grindstone, but it is well also to get accustomed to judging the hardness approximately by the way the metal feels under the file.

Exercise 34. Experiment on tempering steel.

It is generally stated that the colors in the preceding table indicate the proper temperatures for the following objects, respectively:*

No. 1. Lancets.
2. Razors and surgical instruments.
3. Penknives.
4. Small shears, chisels for cold iron.
5. Axes, planes, pocket-knives.
6. Table-knives, large shears.

* Percy's Metallurgy.

7. Swords, springs.
8. Fine saws, daggers, augers.
9. Saws.

As your future exercises give you opportunity, you ought to compare these results with those of your own experience, remembering the agreements, and the differences if you find any, and noticing any peculiarities in the behavior of different kinds of steel, so as to know how to treat different kinds when particular results are sought.

The three pieces tempered in the last experiment may be tested also as to toughness, by holding them one after the other in exactly the same way in a vise, and striking them on one side increasingly heavy blows with the hammer till you break them. No very exact result will be reached in this way, because you cannot measure the energy of your blows; but you can form an approximate estimate of the toughness of the pieces.

LESSON XVII.

HARDENING AND TEMPERING STEEL.—*Continued.*

We come now to consider—

2. The method of applying heat.

When a piece is to be hardened all over alike, it is important that it should have the same temperature throughout. It may, if not too small, be heated in the forge-fire; but it must be moved about, so that all parts may be exposed to the heat, and must be heated slowly, so that all may have time to arrive at the same temperature.

The hollow fire is useful for this purpose, as it allows the piece to be watched closely, and insures the heating of the top as well as the bottom. If the piece is small, an excellent plan is to immerse it for some minutes in red-hot melted lead. The piece quickly takes the temperature of the lead, and care must therefore be taken not to allow the latter to rise to the point at which it would injure the steel. The lead must be watched, and if it is found to be getting too hot, it must be cooled by putting the end of a bar of

cold iron into it. The pieces should be rubbed with soft soap before immersing them, to prevent the lead from sticking; or a paste made of black-lead and water may be used; but in this case care must be taken to let the paste dry before immersing the piece, as otherwise the steam produced may scatter the lead in a dangerous way.

If small objects be removed from the lead with cold tongs, they will be irregularly cooled. It will be well therefore to let the ends of the tongs lie in the lead for some time; or they may be first heated in the fire, and then stood in the lead till wanted; or the piece may be held by means of a piece of soft wire twisted round it as a handle.

The heat for annealing may be applied in the same way as that for hardening. The heat for tempering would be more difficult to manage if it were always necessary that all parts of the piece should have the same temperature, because all will not reach this temperature, or show the corresponding color at the same time. Fortunately, however, this is seldom required. It is always, for instance, the *edge* of a cutting-tool that is to be tempered; the exact condition of the rest of the tool is not so important. It is the *face* of a hammer, the *point* of a drill, the *upper surface* of an anvil, that is to be tempered, and it is on these that the attention is to be fixed while the piece is

being heated. Small objects, therefore, such as drills and knife-blades, may be heated on a hot bar and pushed off at the right time; or small drills may be heated in the blue part of the flame of a candle, applied just behind the point, so that the color of the point may be watched. Larger objects, such as chisels, cold-chisels, hatchets, and rock-drills, may be still more conveniently tempered at the edge by means of the heat left in the rest of the tool after the edge is cooled. The making and tempering of a cold-chisel will afford a good illustration of this very useful method.

Exercise 35. Making a cold-chisel.

Take a bar of $\frac{3}{4}''$ octagon tool steel. Cut off a piece 7″ long by nicking it all round on the hardee at a red heat, cooling it quickly in water, and then breaking it off as in Exercise 26. Be careful not to hit so hard as to make the piece fly, and not to place it in such a position that, if it does fly, it can hurt anybody. Working at a red heat and avoiding overheating, draw one end down to a bevel extending back about $2\frac{1}{2}''$. To do this, hold the piece on the anvil, resting obliquely on it at the farther edge, as in Fig. 56, and strike it with the hammer inclined at a little larger angle. Both the opposite faces

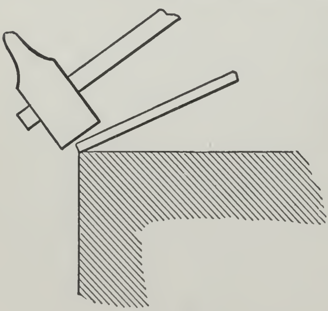

FIG. 56.

will thus be flattened at once. The angle of the faces should be about 16°, which it will be if the thickness of the steel is $\frac{3}{4}''$ and the length of the bevel $2\frac{1}{2}''$. If the angle is much larger than this it will not allow the workman to have a good view of the edge of the tool in using it; if much smaller, the tool will be too thin and will spring too much. In flattening the bar you will, of course, spread it sideways also, as in previous

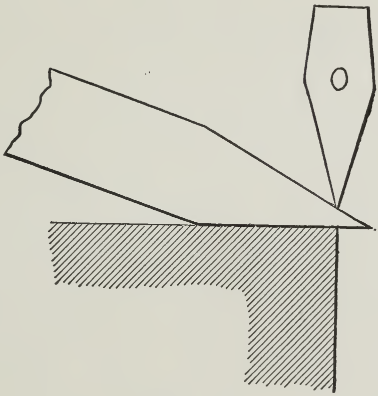

FIG. 57.

scarfing exercises. Reduce the bar again nearly to its former width at the edge, by hammering on the sides. Cut off the ragged edge at a red heat, on the hardee, being very careful not to strike the edge of the hardee with the hard face of the hammer. It will be safer to do this with a hot-chisel and the assistance of a helper. Hold the bar on the anvil with the left hand, the edge projecting

about $\frac{1}{4}''$ over the edge of the anvil. Set the hot-chisel over it, as in Fig. 57, and hold it with the right hand while the helper strikes it with the sledge. Take care that the chisel as it cuts through shall pass just clear of the edge of the anvil, shearing the piece off without injury to the chisel.

You need not be afraid of injuring the steel by too much hammering, or by hammering after it has fallen below the red heat. Unlike iron, it is improved by hard work on the anvil, having no fibres which can be separated by hammering. Finish the faces with the flatter, as in Exercise 18.

You are now ready for the annealing, hardening, and tempering. Heat the whole chisel to a cherry-red, slowly and uniformly, as explained in Exercises 28–30. Hold it in the tongs by the upper end till it has reached a black-red heat, and then plunge it endways, edge first, into cold water, immersing it completely, and leaving it there till cold. The tool is now annealed. All the inequalities of hardness which may have resulted from the different treatment that different parts of the tool have received during the forging are removed, and the whole tool is soft enough to be sharpened with a file.

To harden and temper the edge, raise about 2″ at the cutting edge to a red heat. Holding it in the tongs with the edge downward, lower it into

the water to the depth of about 1″. Then gradually raise it till about half an inch is immersed, and hold it there, either still or moving gently to and fro sideways, till the edge is cold. The object of this movement upward is to prevent a too abrupt change from the cold to the warm part. If the chisel is immersed to a given depth and held steadily there, the boundary between the hard and the soft part is too distinct, and the chisel is almost sure to break at that place.

The edge is now hard—too hard for use, and is to be tempered. Rub one of the surfaces for about $\frac{1}{2}''$ back from the edge with a piece of sandstone to brighten it, and then watch carefully for the appearance of the proper color *at the edge*, as the heat comes along from the other part of the chisel. What the proper color is, depends on the use to which the tool is to be put. We will suppose this one to be intended for cutting cast-iron, in which case the proper color is a light purple. As the colors move along toward the edge, the purple will be followed by the dark blue, and when the latter has almost reached the edge the former will have reached it, and it is then time to plunge the whole chisel into water, and move it about till it is cold. The experiments you have already made have taught you what to do if you require a harder or a softer temper than this.

The cutting-angle of the chisel is formed on the

grindstone, and extends back only about $\frac{1}{8}''$ from the edge. The size of this angle, as well as of that between the two forged faces, depends on the use to be made of the tool. The latter angle may be 12° to 15° for brass or copper, and 16°, as in the one just made, for iron. The cutting-angle should be about 30° to 35° for copper, 50° for brass, 65° for cast-steel, and 80° for cast-iron.

LESSON XVIII.

HARDENING AND TEMPERING STEEL.—*Continued.*

We have next to consider—

3. The method of cooling. The piece of steel, when heated, may be cooled, either for the purpose of hardening or of tempering it, by plunging it into any fluid which is a good conductor. The better the conductor is, the more quickly will the piece be cooled, and therefore the harder will it be. Hence, when the highest degree of hardness is required, mercury is sometimes used. Water, oil, and tallow, which are inferior conductors, give successively lower degrees of hardness. Water is the material most commonly used, and, for pieces which require more toughness and elasticity, as springs and small drills, oil. In tempering also, as well as in hardening, the fluid is varied according to the results sought, water and oil, however, being generally used, and even air when the piece is very small.

To illustrate these points we will make, first, a flat spring, and secondly, a small drill.

For the first, take a piece of $\frac{3}{8}''$ round tool-steel about 10″ long. Heat 3″ of the end, with proper precautions against burning, and flatten it till it is $\frac{1}{2}''$ wide. Make it quite straight, and of exactly uniform width and thickness, using a flatter if necessary. Finish it as smooth and free from scale as possible, as scales will prevent it from heating uniformly all over. With a small punch make two holes $\frac{1}{8}''$ in diameter in one end, being careful not to split the piece in finishing. Bend it as in Fig. 58, by heating the end to a dull red, laying it

Exercise 36. Making a spring.

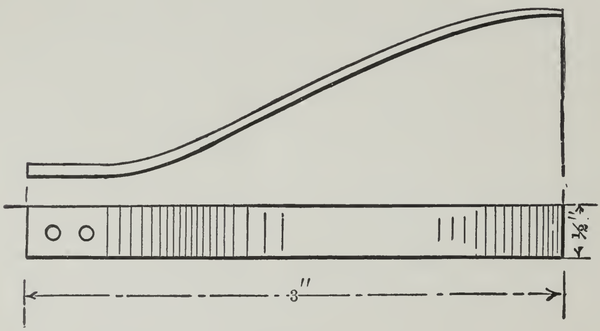

Fig. 58.

over the edge of the anvil, and hammering as in Exercise 5. Be careful not to make the bend too sharp, but rather curved, or you will weaken the steel at that point. Bend the other end in the same way. When the spring is finished, nick the piece with a file at the base of the spring, and,

holding it in the vise, with the nick just visible above the jaws, break it off by bending.

To anneal and harden the spring, provide a jar of linseed-oil four or five inches deep. Tie a piece of light wire 8″ or 10″ long to one end of the spring as a handle. Heat the spring to redness, in melted lead, and let it cool slowly on the ashes beside the fire. Heat it again to redness, and plunge it endways into the oil. If several students are working together, some may try the effect of immersing it sideways. You will probably find that in this case the spring is bent by the unequal cooling of the opposite edges, and will thus learn the advantage of immersing such pieces endways.

The spring being hardened, is now to be tempered. This requires that it be raised to the temperature indicated by a deep-blue color, or about 560° F. The thinness and crookedness of the piece will make it nearly impossible to do this properly, either in the fire or on a red-hot bar. Put it into a ladel of cold oil, and heat it gradually to boiling, with the precautions against accident indicated on p. 89. At various stages in the boiling the oil will have different temperatures, which are easily recognized. When a light white smoke begins to come off, the temperature is about the same as that indicated by a straw-color, or about 450° F. A copious dark smoke is equiva-

lent to a brown color, and a still more abundant black smoke to a purple. At a little higher temperature than this, the oil will burn if ignited, but can be put out by blowing it. This temperature is equivalent to a blue color, and will be suitable for tempering the spring, if it is made of a low-grade steel. At a still higher temperature the oil swells up and boils vigorously, takes fire on the surface and burns continuously, igniting again if blown out. This temperature is suitable for the spring if it is made of high-grade steel. At the proper temperature, remove the spring from the oil by the wire handle, and cool it in the air, in water, or in cold oil. The difference between these methods will be slight in such a small piece. Set the oil aside in the forge till it cools off, after which it can be put away for future use.

To test the spring, hold it in the vise by the end, straighten it, and let it go two or three times. It should completely regain its figure. If it breaks, it is too hard, and the tempering heat was not high enough. If it does not return, it is too soft, and the heat was too great.

Exercise 37. Making a drill.

As a last exercise in forging and tempering steel, make a small drill ($\frac{1}{8}''$) such as is shown, enlarged, in Fig. 59. Take a piece of steel wire $\frac{3}{16}''$ thick and $6''$ or $8''$ long. On a small bench anvil, and using a light hammer, draw it out, at a dull-red heat to

the form shown in Fig. 59. The flame of the Bunsen burner may be used for this, or the forge-fire, if very great care is taken. First draw out the narrow part, or shank of the drill, turning it constantly to preserve its roundness and keeping it quite straight. Next flatten and widen the end. Finish it smooth, cut it off, and anneal it at a black-red heat. Finish the flat faces on the grindstone, and then form the two bevelled surfaces, by holding it on the grindstone or the emery-wheel as in Fig. 60, cutting it back to the dotted line, and then turning it over and cutting to the other dotted line. Observe that the faces that you are now forming are to be, as shown at B and C, not perpendicular to the flat faces, but inclined to them

FIG. 59.

The inclination, which constitutes the cutting-angle of the tool, depends, as in all other cutting tools, on the hardness of the material on which it is to work. If, as you hold the drill between the

thumb and finger in grinding it, you turn the thumb a very little over toward the right, you will make a drill suitable for one kind of work, and if you turn it a little farther, one suitable for softer material. Your drill, when finished, will have, as you see on examining the figure or the drill itself, not a point, but a short blunt edge, running obliquely across the end, as shown in the end elevation *C*.

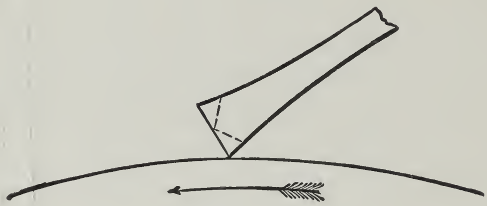

FIG. 60.

The drill is now to be hardened and tempered. To harden it, hold the point in the flame, watch it till it reaches a cherry-red, and then plunge it into water. The butt of the drill will thus be left soft. Brighten the point, and hold it again in the flame, the point being this time just outside, so that the color can be seen. The color, which, in the case of such a small piece as this, will appear very soon, should be brownish yellow if the drill is intended for iron, and purple if it is for wood. The moment the color appears, plunge the drill quickly, point downwards, into cold oil.

The final finishing on the grindstone is done after the tempering.

A still smaller drill may be hardened by heating the point in a candle-flame, and cooling it in the tallow of the candle. It is then tempered, by covering the point lightly with tallow, holding the stem just behind the point in the flame till it begins to give off a white smoke, and then cooling it either in the tallow or in the air.

The exercises in hardening and tempering that you have now gone through will give you a sufficient comprehension of the general principles of the process. A great variety of modifications of the methods will be needed for works of different sizes and shapes, and intended for different uses; but these will be easily understood when the necessity for them arises.

It might be supposed that, as cast-iron differs from steel in the same way that steel differs from wrought-iron, namely, in having more carbon in its composition, it might be hardened and softened in the same way. This is to a certain extent true. Cast-iron can be hardened by rapid cooling; but it requires a much higher temperature for the purpose than steel does. It must be cooled, not merely from a red heat, but from the melting heat. If cast-iron, when melted is poured into moulds of damp sand or of metal, it becomes very hard on the surface. Such metal is called "chilled

iron," and is sometimes used when great hardness is required at moderate expense, and without regard to toughness, as in ploughshares, ore-stamps, rollers for pressing or crushing, and sometimes in tools for turning iron and steel. Such metal, however, is brittle and cannot be tempered, and is not a fit substitute for steel in most of the uses to which the latter is put.

Even when cast-iron is not intentionally chilled, it is unavoidably hardened on the surface by the chilling action of the mould, and this is one of the reasons why the hard "skin" is commonly removed with the chisel or planing-machine before applying the file.

As cast-iron can be hardened by chilling, so wrought-iron can be hardened on the surface by baking it, at a red heat, while surrounded with powdered carbon. The resemblance between this process and that of steel-making by cementation is seen at a glance. Indeed, it is an imperfect conversion of the iron into steel on the surface. It is called "case-hardening," and is used for such objects as the wearing parts of gun-locks, the ends of axles, and other objects exposed to great wear by rubbing.

Finally, as wrought-iron can be hardened, so, by an almost exactly opposite process, cast-iron can be softened. As wrought-iron is hardened by absorbing carbon, so cast-iron is softened by

being made to give up carbon. For this purpose it is packed in a substance containing oxygen, such as lime (calcium oxide) or the scales from the blacksmith's forge (iron oxide), and baked at a red heat. A part of the carbon combines with the oxygen, and escapes as carbonic oxide, leaving an iron with a lower percentage of carbon, and therefore resembling wrought-iron or mild steel. Such iron is called "malleable" iron, and is much used for small articles which require more toughness than cast-iron possesses, but which are to be made in large numbers, and with a cheapness approaching that of cast-iron. Hinges, gate-fixtures, parts of harness, and a great number of small household articles are made in this way.

It must be understood, however, that not every kind of pig-iron can be used for the several kinds of iron that have been described, but that one pig or another, or a mixture of several, must be used, according as high or low steel, foundry iron, chilled iron, good forge iron or malleable iron is required; and great skill and experience are necessary to enable the iron-manufacturer to make the proper selection in each case.

LESSON XIX.

CHIPPING.

Objects made of iron, steel, or brass by casting are frequently too rough to be used in the form in which they come from the mould, and have to be finished up by filing, grinding, scraping, and polishing. Sometimes, also, it is necessary to take off more metal than can be conveniently removed by the file. On large and flat surfaces this may be accomplished by means of a planing-machine; but on surfaces that are small, or of such a shape that the planer cannot reach them, the part to be removed is taken off by "chipping" with a cold-chisel, that is, a chisel which can be used without first softening by heat the substance which is to be cut.

Two kinds of chisel, shown in Fig. 61, are used. The first, *A*, called a "cape" or cross-cut" chisel, is made thin at *c*, but is widened, as shown at *a*, to give it the needed strength. It is used in cutting grooves. Being thinned at a little distance back from its edge, it can be driven along the

groove without catching at the sides, while the extra width at *a* prevents its "springing" under the blow. The other, *B*, is the "finishing" or "planing" chisel, and is used for cutting broader plane surfaces. It is sometimes ground with a slightly

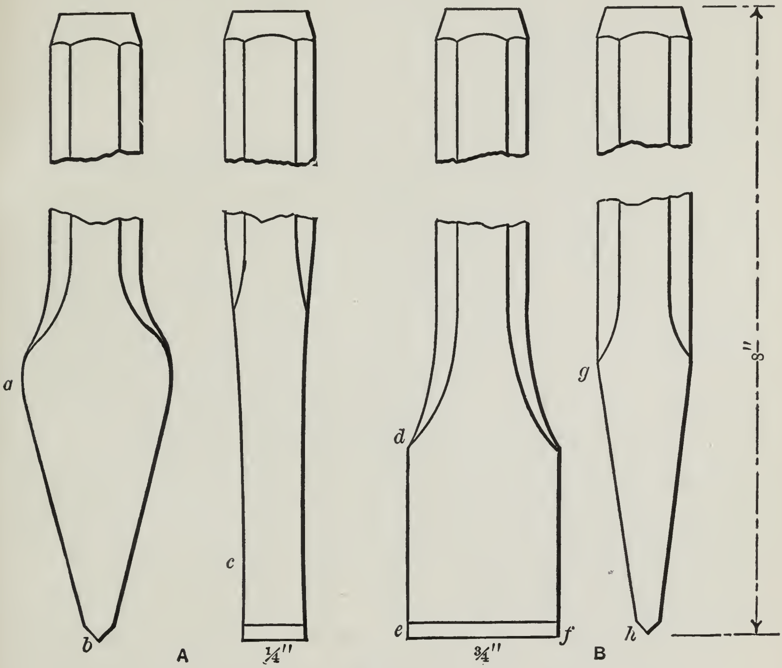

Fig. 61.

curved edge, in which case a very thin cut can be made at the middle while the corners are not cutting at all. Its action in this case is much like that of the jack-plane, and leaves a series of shallow valleys on the surface that is finished with it.

The chisel is tempered, as in Lesson XVI, to a color which may range from yellow to purple, according to the work it is to do. It will splinter if it is too hard, and will turn up or become rounded on the edge if too soft, and must then be re-tempered. In any case, its edge must be kept sharp by frequent use of the grindstone. The angle also depends on the kind of work, as has been explained in Lesson XVII.

Exercise 38. Chipping cast-iron.

As an exercise in the use of the chipping-chisel, we will remove $\frac{1}{4}''$ from the surface of a cast-iron block $3''$ square. We will first cut three grooves $\frac{1}{4}''$ wide to the required depth, leaving four surfaces $\frac{9}{16}''$ wide to be afterwards cut down with the finishing-chisel. It will be found that the work can be done more easily in this way than by cutting the whole surface at once with the finishing-chisel. Lay out the face of the block for this work by first rubbing it all over with chalk, and then drawing the necessary lines with a sharp-pointed steel "scriber" or marking-tool. Mark also, on the edge, a line showing the depth to which the work is to be cut. Put the block in one of the heaviest vises on your bench. If there is a "leg-vise," Fig. 62, use this, as being firmer than any other. Place the block in the vise, with the lines indicating the grooves perpendicular to the jaws, and with the upper surface of the block only just

above the edge of the jaws, and fasten it very firmly. Make sure that the head of the chisel and the face of the hammer are quite free from any trace of grease, by rubbing them on the dusty

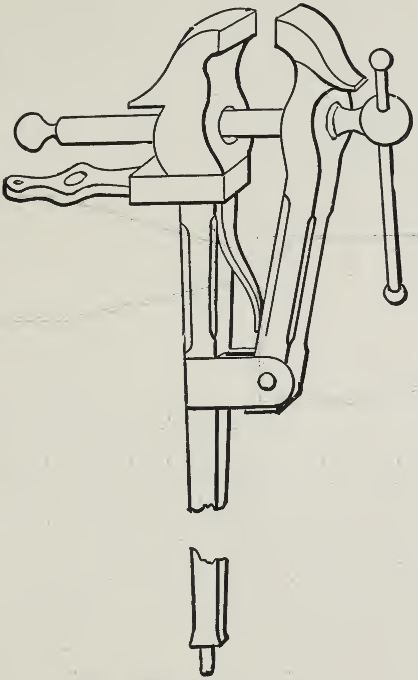

FIG. 62.

floor. You will thus lessen the chance of the hammer's glancing off and striking your hand.

In vise-work hold the hammer less tightly than in forge-work. Let it turn somewhat loosely between the forefinger and the thumb.

To begin the chipping, set the edge of the

chisel at one end of the line drawn on the face, and, holding it horizontally, strike it a vigorous blow, cutting off a triangular chip, and making a chamfer or bevel, as shown by the dotted line in Fig. 63. Extend this along the whole length of the end of the block, thus marking conspicuously the depth to which the metal is to be removed. Turn the piece in the vise, and cut a similar chamfer round each of the other pieces in succession.

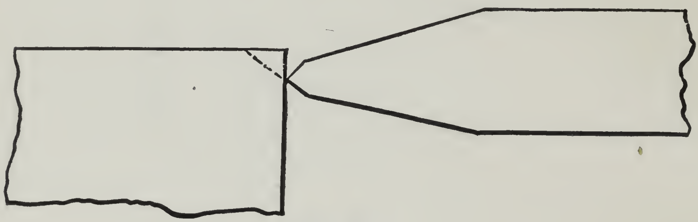

Fig. 63.

Now, using the cape-chisel, set it on the bevelled surface, at the end of one of the proposed grooves, and with the edge about $\frac{1}{8}''$ below the upper surface, as in Fig. 64. Incline the handle upwards, so that the lower cutting-face shall make a very small angle, *abd*, with the intended direction of the cut, *abc*. Hold the chisel firmly, near the upper end, and keep your eye on the cutting-edge, not on the handle. Using a hammer of about $1\frac{3}{4}$ to $2\frac{1}{2}$ lbs. weight, with a handle $13''$ to $14''$ long, which you hold near the end, strike the chisel with a vigorous swing of the hammer from the elbow. Be careful to strike exactly in

the direction of the length of the chisel, so that it shall not receive any twist from the blow, but move directly forward. It will cut off and curl up a stout chip, exactly as the iron of the jack-plane does, and being continually driven forward, will work a shallow groove across the block. It is important that you should hold the chisel at the proper inclination. If the handle is held too

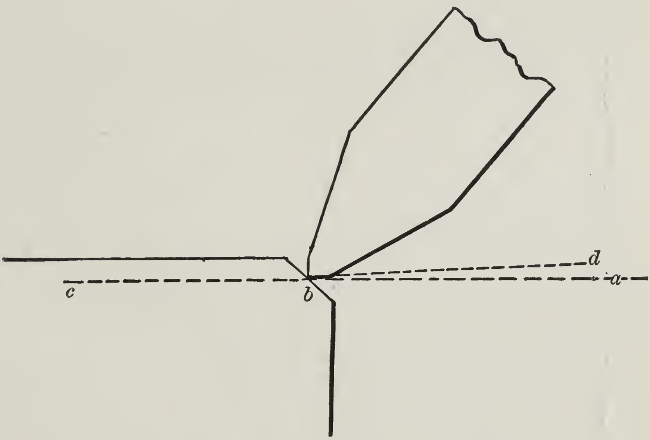

Fig. 64.

low, as in Fig. 65, the edge will be inclined upward at b, and the tool will run up and leave the cut. If it is held too high, as in Fig. 66, the point will be driven too far into the metal, and the cut will become so deep that the chip will not curl up and break off, but the tool will be brought to a standstill.

After the cut is started, you will *feel* the proper

position of the chisel, by rocking it up and down slightly, as you would rock a wood-chisel on the oil-stone, to ascertain when the bevel-surface touches the stone properly.

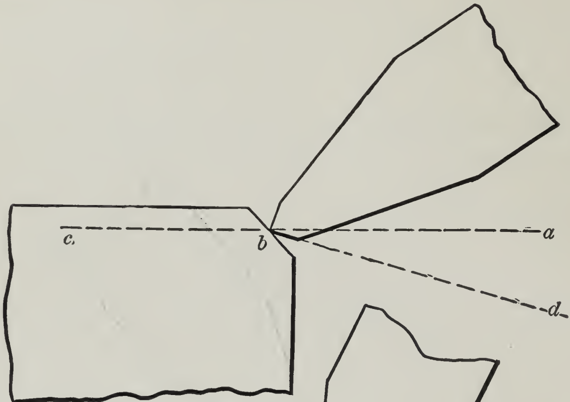

FIG. 65.

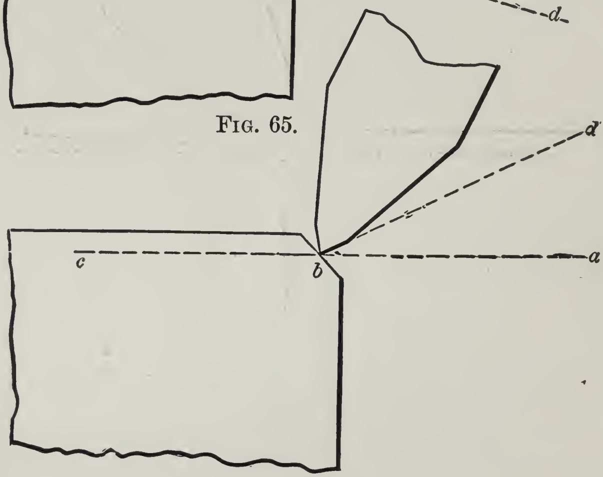

FIG. 66.

It is important, also, to strike powerful blows with a free swing of the hammer from the elbow. Light blows often repeated will not serve the same purpose: they will not cut and shatter the

metal. You may strike light blows at first, to get your aim sure and your hand steady, but they will not have much effect on the metal. Even at the risk of striking your left hand occasionally, you must hit hard.

In cutting the grooves, stop at about $\frac{1}{4}''$ from the end, and cut the opposite way, to avoid splintering the metal.

In cutting wrought-iron, steel, or brass, wet the edge of the chisel occasionally, by pressing it on a bit of wet rag or cotton-waste kept for the purpose.

A second and a third cut being made in the same way as the first, you will cut one of the grooves, and afterwards all the others, down to the required depth. Be careful not to go below this depth at any point; to fall short of it will do less harm.

Having cut all the grooves with the cape-chisel, cut down the bands between them with the planing-chisel. If you have cut the grooves to just the right depth, they will afford such perfect guidance to your chisel that you will cut the rest of the surface with comparative ease.

If the work has been well done, the surface will be uniformly marked all over with parallel shallow notches, about equidistant and of equal depth, indicating the successive forward steps of the chisel. In perfect work, indeed, no such

notches would be seen, because each forward movement would be in the continuation of the preceding cut. In practice such a result is not to be expected; but you should aim to come as near it as possible.

The chipping of brass is similar to that of cast-iron. The tool, however, may be thinner, and have a smaller angle, as already explained. It may also be wider (say 1″), as the same blow that will drive a narrow chisel through cast-iron will drive a wider one in brass. For an exercise in brass-chipping, take the block prepared as a foundry exercise, page 64, Fig. 50, and chip it to the form of a hexagonal prism.

First, whitening the ends, lay out the bases of the prism. Find the centre of each end by drawing diagonals, and mark it lightly with a centre punch. With a compass, draw round this the inscribed circle. From *a*, Fig. 67, draw a line on the rectangular face of the prism, parallel to the edge, thus finding the corresponding point on the other base, and draw the inscribed circle. Starting from *a*, lay off chords equal to the radius, finding thus the points *b*, *c*, *d*, *e*, *f*. Draw the hexagon on each end of the piece. Connect the vertices *aa* and *dd* of the two hexagons, by lines drawn

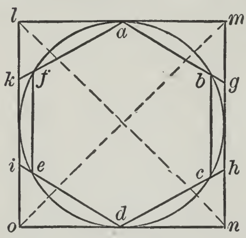

Fig. 67.

on the faces of the block. Prolong *ab*, *dc*, *af*, *de*, as in the figure. Connect the points *gg*, *hh*, *ii*, *kk*, of the two bases by lines on the faces of the block. If now you cut off first the four pieces which have the bases *amg*, *hnd*, *doi*, and *alk*, you will make a hexagonal prism, whose bases, however, are not regular. On the faces of this prism draw *bb*, *cc*, *ee*, and *ff*, and cut away the parts whose bases are *bghc* and *kfei*, and the prism will be complete.

Exercise 39. Laying out a hexagonal prism.

To cut off all these parts, first hold the block endways in the vise, its edges perpendicular to the jaws and the line *ag* parallel to them. Beginning near *m*, cut off a piece along the whole edge *mm*, just as in the last exercise. As the chisel approaches the end of the cut, turn the piece round and cut in the opposite direction, so as not to splinter the base. Repeat this till you have cut down to *ag*, being careful not to go beyond. The first cuts, being narrow, may be deeper than the succeeding ones. Repeat this operation at the other three corners. Then, having drawn the new lines *bb*, *cc*, *ee*, *ff*, cut off the remaining portions in the same way. If you have not cut quite down to the required surfaces at first, you may use a thinner and sharper chisel and a lighter hammer for the finish, making constant use of a straight-edge and a "template" or plate of brass, Fig. 68, whose

Exercise 40. Chipping brass.

angle is 120°, to make sure that you are not cutting anywhere too deep. Having made one face as straight and smooth as possible, and free from winding (Wood-working, page 54), apply the template repeatedly to this while working the next face, so as to give the next the proper inclination to this. When the two faces adjacent to the first are finished, give the next two the proper inclination to these. If this has been correctly done it will be easy to give the last face the proper inclination to the two preceding ones. In

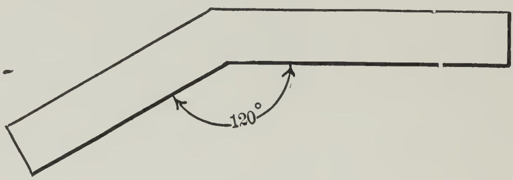

FIG. 68.

applying the template, it is of the utmost importance that both arms of it should be exactly perpendicular to the edge of the prism which lies between them; otherwise you will make the angle of the prism too obtuse. Very close attention to this is absolutely necessary, as is also perfect correctness in the angle of the template itself. Of course, if the two bases have been drawn exactly correct and with their corresponding sides parallel, you have only to cut down to these lines and then work with the straight-edge alone, the template

being unnecessary; but your work will hardly be exact enough for this.

The faces of the prism being finished, the bases are to be cut off in the same way, perpendicular to the faces, and $2\frac{1}{16}''$ apart, the work being tested as it proceeds with straight-edge and square. The result should be a true hexagonal prism $2\frac{1}{16}''$ high, its opposite faces being equal and parallel rectangles, its edges straight, and its angles all equal to that of the template. There should be no marks extending conspicuously below the general surface so that they cannot be easily removed by the file, as in a later lesson.

LESSON XX.

DRILLING AND SAWING.

In the chipping exercises just finished, no large amount of metal had to be removed, though the quantity to be cut away was larger than it would

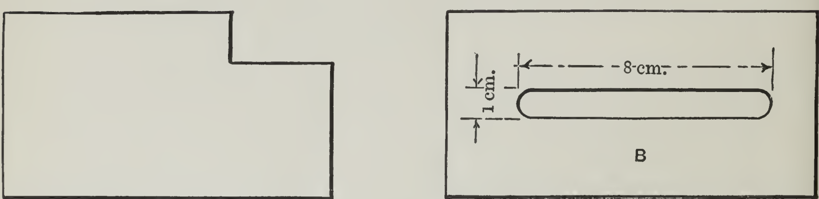

Fig. 69.

be proper to attack with the file. In some cases a larger piece has to be removed, as when a corner is to be cut out of a block of metal *A*, or a slot to be made in one, as *B*. In such a case the piece is cut out with a "hack-saw," Fig. 70. The teeth of this saw have their front edges perpendicular to the edge of the saw, and their back edges inclined to it, as in the rip-saw (Wood-working, p.

83). They therefore cut under the metal, somewhat as a chipping-chisel does, removing the metal in small chips, like the saw dust from a wood-saw. Its teeth have no "set," as those of wood-saws generally have, but are sometimes made a little thicker than the back of the blade, by setting the saw up on its back edge on a block of hard wood before sharpening it, and hammering the points

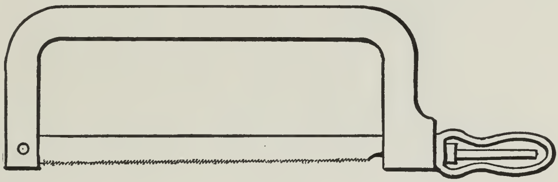

Fig. 70.

of the teeth lightly. This not only spreads them out sideways and gives the tool the extra thickness on the edge which makes it run freely, but at the same time brings the points of the teeth into a straight line. This is very essential to the proper working of a saw, whether in wood or in metal. If any of the teeth stand up above the rest, they catch in the work and make the saw jump and "chatter." Sometimes this thickening of the edge of the teeth is omitted, the "burr" or roughness left by the file being sufficient to give the needed "set."

Exercise 41. Drilling.

The cutting of the slot *B*, Fig. 69, in a plate of $\frac{1}{2}''$ brass will be a good exercise in the use of the saw and of the "ratchet-

drill." The slot is commenced by boring two holes for its ends with the hand-drilling machine, Fig. 71, or the ratchet-drill, Fig. 72. Mark the exact positions of the centres of the holes with a centre-punch. Provide a drill 1 cm. wide, such as you made in Exercise 37. If you have not one of exactly the right width, alter a wider one, by reducing it on the grindstone, being careful to reduce both sides equally.

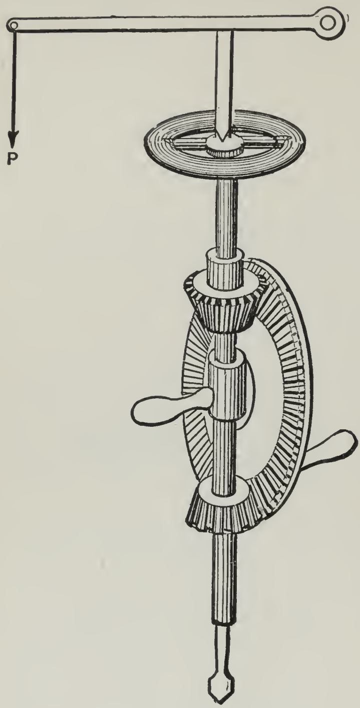

Fig. 71.

The ratchet-drill is made in various forms, but the essential principle of all is the same. The work to be drilled rests, at *A*, on blocks supported on the frame-work *B*, which may be screwed to the bench. A screw *C*, which must be turned by hand as the boring progresses, or else a lever worked by the hand of an assistant, presses the drill *D* down. A lever or handle *E*, provided with a spring "pawl" concealed in the box *F*, turns on the axis or shaft of the drill. The pawl

slips by the teeth of a toothed wheel which is attached to the axis, when the handle is turned in one direction, but catches the teeth and turns the drill when moved in the opposite direction. The hand-drilling machine, Fig. 71, is used for the same purpose, and is even more convenient.

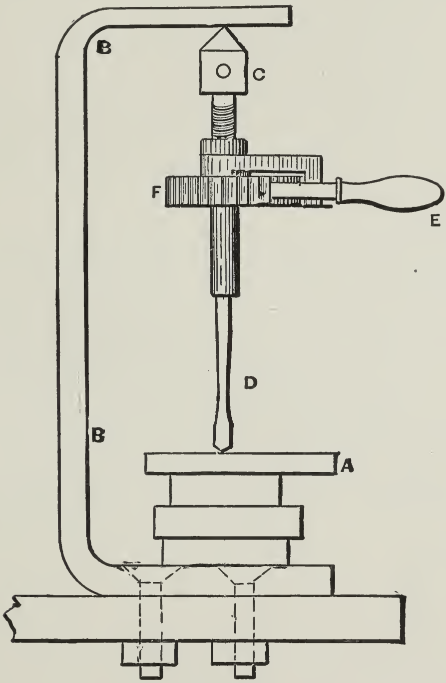

FIG. 72.

Setting the plate on the bottom of the framework of the drill, and supporting it on blocks, if necessary, to raise it to the proper height, turn the screw at the top till you bring the point of the

drill down into the hole made by the centre-punch. Fasten the work so that it cannot turn. Turn the drill by means of the handle, and keep moving it down at the same time by means of the "feed"-screw. Lubricate the point with oil or with soap and water in cutting brass, wrought-iron, or steel; for cast-iron this is not necessary. Do not "feed" or force the drill forward too fast, or you will break it, or spoil its temper. Let the drill, when it comes through, come out into a hole in the support, or else have a block of wood immediately under the work.

Exercise 42. Cutting a slot.

The two holes being bored, draw two parallel lines tangent to them with the scriber, thus marking the size and shape of the piece to be removed. Holding the piece in the vise, and using a square file, cut one of the holes to the shape shown in Fig. 73, forming thus flat sides against which the sides of the saw can rest. Loosening the screw at the end of the saw-frame, unhook the saw, put the blade through the hole, hook it and tighten it again, and cut down to the other hole. Use oil to make the saw work freely, except in cast-iron. Do not press too hard, and be careful not to run outside of the line.

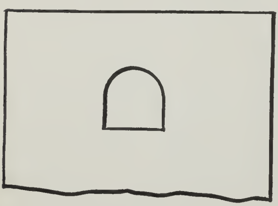

Fig. 73.

The first cut being made, carry the saw back

to the first hole, and cut the second line in the same way. The piece between the lines being removed, the roughly framed slot can be finished with the file as in the next lesson.

Such a piece is sometimes removed by boring a series of holes close together along the whole length of the slot, and then cutting away the metal between them with a round file.

LESSON XXI.

FILING.

After chipping and sawing, the work is ready to be smoothed with the file.

The file is a series of small chisels, finer or coarser according to the work required of them. These minute chisels are made by cutting numerous fine grooves very close together in a bar of steel shaped as in Fig. 74. If only one such set of grooves is cut, the file is called a "single-cut" file or "float," and appears as shown in the upper part of Fig. 74, A. The appearance of the teeth is shown, magnified, at D. The whole face of the file is thus a series of chisels, each having a breadth equal to the length of one of the lines in A, inclined to the axis of the file at an angle of 35° to 55°, and having their sharp edges turned towards the point of the file. Files of this sort are only used for soft materials, such as wood, horn, and lead. When very coarse, as in the case of the files used for lead, the cuts are almost perpendicular to the length of the file. The files used for such work as you will undertake, or for metal-work in gen-

eral, have two such sets of grooves, and are called "double-cut." The first cuts are made as already described, and the second, which are not quite so deep, cross these, as shown in the lower part of

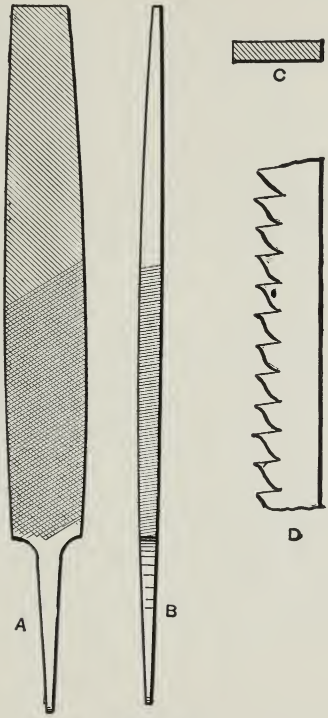

FIG. 74.

the figure, being inclined to the axis in a direction opposite to the first, at an angle of from 75° to 85°. The wide chisels of the first cut are thus divided into a large number of small-pointed teeth. The teeth of any one row being pushed across the

work would make a series of fine grooves; but the teeth of the next rows following these, cut down the ridges between these grooves, and so gradually plane the work down.

Double-cut files have various names to distinguish the degrees of fineness or the closeness of the grooves. These names differ somewhat in the different regions in which files are made, the Lancashire names and the Sheffield names, for instance, being not exactly the same. Without learning both series of names it will be sufficient to remember that, in both sets, the coarsest files are called "rough," and the very fine ones "smooth." Intermediate ones, following the rough, are "bastard" and "second-cut," and a still finer kind than the smooth are called "dead-smooth" or "superfine."

It may be remembered also that the "rough" Lancashire files have from 21 to 56 cuts to the inch, the "smooth" from 56 to 112, and the "superfine" as many as 300 in the case of the smallest files.*

The grooves are cut with a chisel while the file is soft, and it is then hardened and tempered according to the kind of work it is to do, and the "tang" or pointed end is softened to prevent its breaking.

The description of the mode of cutting the

* Holzapfel: Turning and Mechanical Manipulation.

teeth of a double-cut file, or an inspection of the teeth with a magnifying-glass, will convince you that files are delicate tools, and that they can be easily injured by improper treatment. A few precautions may be given here to enable you to avoid the commonest errors, and others will come to your notice afterwards, as your work progresses.

1. A new file must not be used on wrought-iron or steel. These can be cut with a file that is partly worn, but cast-iron and brass require new and sharp files.

2. No file, unless it be one that is almost worn out, should be used on chilled castings. The surface of a casting should be carefully tried with an old file, and if it is found to be very hard, the skin must be removed on the grindstone.

3. No file should be used on castings, whether hard or soft, in the state in which they come from the foundry. The surface is covered with sand, which will spoil any file. This is sometimes removed by "pickling" in dilute sulphuric acid, which eats away a portion of the iron and loosens the sand so that it can be washed off. When the figure of the casting is such that the surface cannot be reached by the grindstone, this is the only effectual method, except chipping, of preparing the work for the file.

4. The file should always be relieved from pres-

sure while it is being drawn back, as heavy pressure on the backs of the teeth breaks them off. It is not necessary, however, to lift the file from the work, but only to lessen the pressure.

5. The teeth of the file should be kept clean. They are apt to become "clogged, or "pinned" by

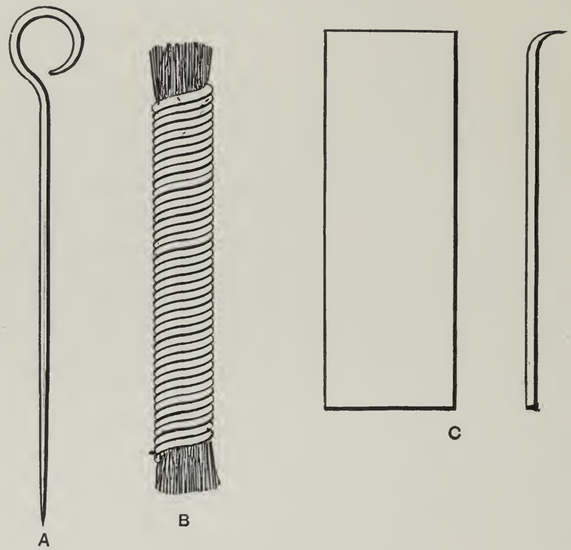

Fig. 75.

the dust cut off, which must then be removed. This can be done in several ways. The "pins" may be pushed out with a pointed steel wire, Fig. 75, A. They may be brushed out with a wire file-brush, B, of fine brass or steel wire, bound into a bundle with the ends projecting; or they may be raked out with the scraper, C, made of a piece of sheet-brass hammered to an edge and bent at right

angles, into which the teeth of the file will cut when it is drawn over them, allowing the intermediate points to penetrate into the grooves and clear them.

The file should be fitted with a handle of soft wood. To put the handle on, hold the file in the vise, protecting it from the steel jaws by false jaws of lead, A, Fig. 76, and leaving the tang projecting forward. Then, taking the handle in the hand, push the tang into it, turning the handle at the same time, to let the tang bore its way. Take the handle off and knock out the shavings, and repeat the operation till the tang has entered about three quarters of its length, or a little more, leaving the rest for future use as the handle wears loose. The handle is sometimes fitted by heating the tang to redness and pushing it in, letting it burn its way. This method is objectionable, however; first, because of the risk of overheating the file, and secondly, because the charred wood wears away soon, and lets the handle come loose.

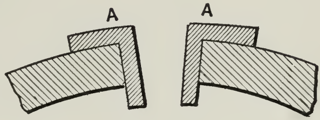

FIG. 76.

Besides the differences in the teeth of files, there are differences in size and shape, adapting them to different kinds of work. The files that will be most useful in such work as you will do are such as are shown in Fig. 74, and are called "taper-

flat." Their cross-section is rectangular; but they are not of equal section throughout, being tapered both in breadth and thickness, and swelled or "bellied" in the middle. They vary in length from about 4 to 24 inches, and will be most convenient for your work if about 10 to 12 inches long. With such a file you may now produce a smooth, plane surface on the cast-iron block of Exercise 37. Use a somewhat coarse file for the first steps of the work, and afterwards, for finishing, a finer one. Put the block in the vise with the chipped face about $\frac{1}{4}''$ to $\frac{1}{2}''$ above the jaws. For work such as this the vise ought to be at such a height as to bring the work about to the level of the elbow. For much larger work it should be lower, to enable you to throw the weight of the body on the file, and for very small and fine work, higher, to allow you to see it more distinctly. Spread your legs apart a little, clasp the file in the right hand, the fingers being below and the thumb on top, hold the point of the file between the thumb and fingers of the left hand to press it down, and push the tool forward. The length of the file should point not straight forward, but a little towards the left, and the movement of the hand should also be a little towards the left as well as forward, but with occasionally a few strokes towards the right to prevent the teeth from follow-

Exercise 42. Filing a plane surface.

ing their old tracks and scratching the work too deeply.

The principal difficulty in using the file is to move it forward without giving it a rocking motion—a difficulty about the same as that encountered in using the jack-plane (Wood-working, p. 64). If you lower the point as you push it forward and raise it as you draw it back, as you will find yourself inclined to do, you will cut off the front and rear edges of the work more than the middle, and will produce a curved surface; but if you keep the file quite level and move it with long strokes, you will cut equally across the whole breadth, and produce a plane surface. Test your work with respect to this point from time to time as you proceed, by applying a "straight-edge." It will not be enough to apply the straight-edge in one direction, parallel, for instance, to A B, Fig. 77, because it is possible for the lines A B, C D and E F to be all straight, and yet the surface not to be plane but to have two opposite corners, as A and F, higher than the others. Neither is it sufficient to apply the straight-edge parallel to one of the diagonals; but if it is applied parallel to both diagonals and both edges, it will be impossible for

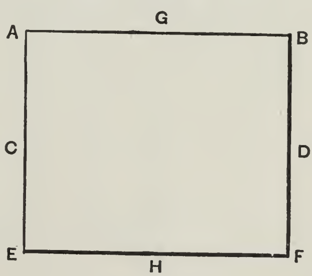

Fig. 77.

it to touch along all these lines if the surface is warped, or "in winding." Trying the surface, therefore, in all directions, and removing the high parts carefully with the round or bellied part of the file, and with lighter and lighter strokes as the piece becomes more and more nearly true, you will finish it at length to a true plane, or as nearly so as it is practicable to make it with the file.

As another exercise, involving greater difficulties than the last, you may now finish up the hexagonal prism of brass made in Exercise 39.

Exercise 43. Filing up a hexagonal prism.

You will make, 1st, one of the hexagonal bases plane and perpendicular to the faces of the prism; 2d, the other base plane, parallel to the first, and at the proper distance (2″) from it; 3d, one of the rectangular faces plane, of the proper width, and perpendicular to the bases; 4th, two adjacent faces plane, of proper width, perpendicular to the bases, and inclined at the proper angle (120°) to the first face; 5th, the last three faces plane, parallel to the first three, and of the proper width.

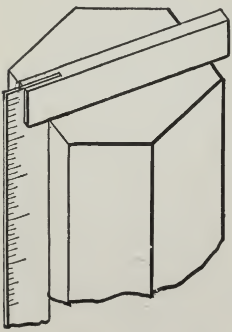

FIG. 78.

First try with a square, as in Fig. 78, whether one of the bases is perpendicular to the six faces. If either of the angles is acute, the base is to be

filed off at this place. Holding the block in the vise, file the base true as in the last exercise, using a coarse file first and afterwards a new and fine one, and trying the surface in all directions with a short thin-edged straight-edge while working, and without removing the piece from the vise for the purpose.

When this surface will bear every test, proceed to the next—the opposite base. Since this is to be made parallel to the first, whether that is perpendicular to the faces or not, it is to be tested, not with the square, but with the straight-edge and the calipers, Fig. 79. They are opened to the width of exactly 2″, and are to be applied to the work repeatedly as the second surface approaches completion, to prevent the cutting away of more than the proper amount of metal. Before the piece is ready, however, for the use of this tool, it is to be first marked to the proper height, and then cut down close to the mark. The rectangular faces being too rough to show a fine mark, may be first filed smooth enough for this purpose. To avoid injuring the finished base in this operation, use the false jaws of lead or brass. Be careful, in this

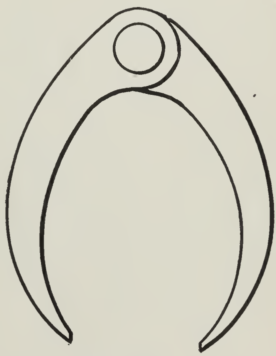

Fig. 79.

first filing of these faces, to take off no more than just enough to enable them to show a fine mark. Chalk the sides. Set the piece up on its finished base, on a "surface-plate." This is a square plate or block of hard cast-iron, which has been finished as nearly as possible to a true plane surface, and serves as a standard of comparison for other surfaces which are to be made plane. The prism being set on this, is held firmly with one hand, while the "scriber block" S, Fig. 80, is held on the plate with the other hand, and the "scriber-point," P, after being set to the exact height of 2″ above the base by the screw V, is carried carefully round all the faces of the prism, making a fine mark. Then, holding the prism in the vise, chamfer the upper base down to this mark, and cut it down, first with a coarse and afterwards with a fine file. As you approach the mark, work more and more carefully. When very near the mark use the calipers frequently at all points of the two bases, till the prism measures exactly the right height at all points. Be careful not to force the calipers, nor yet to make them go on too loosely. They must just touch closely, and so that no rattle is possible. If the joint is tight, as it ought to be, the width between the points will not be altered by sliding them on and off repeatedly, unless considerable force is used. Furthermore, they must be held in

Exercise 44. Use of scriber and calipers.

the proper position while being used. If one point is farther advanced on the surface than the other, as at A, Fig. 81, you may work the piece

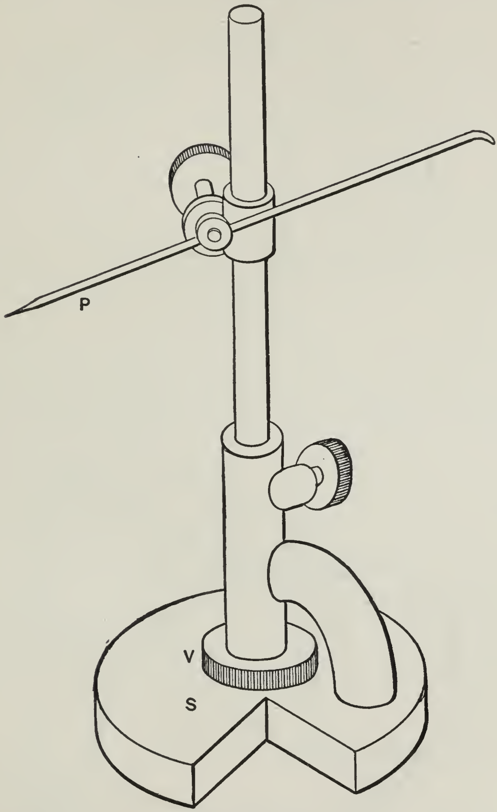

FIG. 80.

too short; and you will do the same if one is inclined to the right of the other, as at B. In short, the line joining the two points must be exactly perpendicular to the two surfaces, and when it is

held thus, the two points must just touch both surfaces. Finally, the calipers must be handled

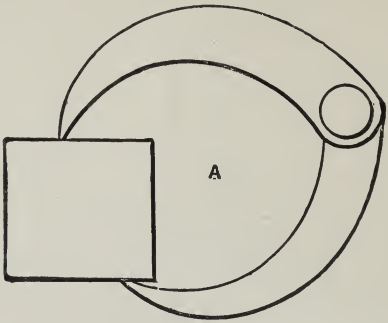

FIG. 81, A.

carefully, being laid down on the bench gently, so as not to alter their adjustment, and must be

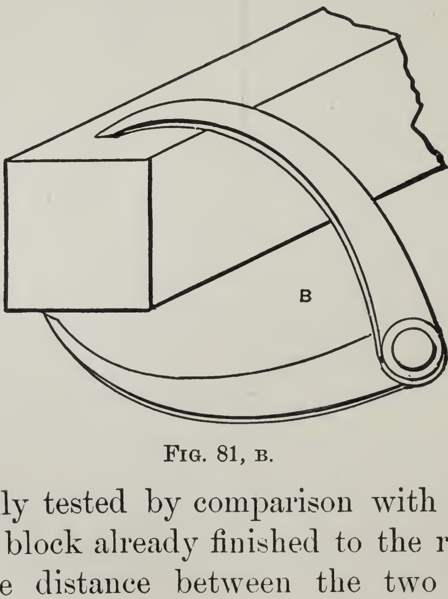

FIG. 81, B.

occasionally tested by comparison with the rule, or with a block already finished to the right size. When the distance between the two bases is

everywhere exactly 2″, the second surface is parallel to the first, and is plane, provided the first is so. You should not neglect, however, to apply the straight-edge in all directions on the second surface, as an additional test. This may be done without removing the piece from the vise, if you stoop down, so as to see under the edge.

Protecting the finished bases by false jaws, file up one of the faces. The process is essentially the same as before, but even more care is necessary, to avoid filing away too much. As all the lines previously drawn on the bases have been filed away, it will be well to draw them again, but very lightly, with sharp-pointed compasses and a marking-awl, and then take care not to work beyond them. When one of the rectangular faces has been finished, the template should be used, as well as the straight-edge, in filing the others, care being taken, however, to test the correctness of the template, and to apply it properly, as explained in Exercise 39.

If properly finished, the prism will stand the following tests:

1°. All the surfaces, as tested with the straight-edge, will be true planes.

2°. Each pair of opposite surfaces will be parallel, as shown by the calipers.

3°. All the faces will be perpendicular to the bases, as shown by the square.

4°. All the angles will be true, as measured by the template.

5°. All the faces will be of equal width.

6°. All the edges will be straight and sharp, and all the surfaces smooth, and free from coarse scratches, showing only the fine and regular marks of the file.

Other methods of producing a finer finish on surfaces, known as draw-filing, scraping, grinding, oil-finishing and polishing, will be explained hereafter.

As a last exercise in filing, finish the slot that you began in Exercise 41, making it 84 mm. × 12 mm. The surface being in this case narrow, considerable care will be needed to avoid cutting off one edge more than the other, and you must look frequently at the back of the work to see that you are not passing the mark. You will lessen the trouble of this part of the work, if, as in working to a mark in general, you first cut, on each side, a chamfer down to the mark, which will then serve as a guide. The ends of the slot, which were left round by the drill, are to be filed square with the edge of the file. After the ends are finished, if any more work is to be done on the sides, for the purpose of finishing up the corners sharp and clean, the "safe edge" of the file which has no teeth, should be used in the corner, so as to avoid injuring the finished end. If the file has

no safe edge, you can make one by grinding off the teeth on one edge. This will be even better than the safe edge made by the manufacturer, as the teeth on the face will come up more sharply to the edge, and will finish the corners better. The tests of the work are obvious. The sides and ends must be straight and plane, and perpendicular to the face of the plate and to each other, and the slot must be exactly true to the proposed dimensions, 84 mm. × 12 mm.

LESSON XXII.

SOLDERING. BUNSEN BURNER.

We have now learned how to give approximately any desired form to wrought-iron or steel by forging and welding, and to cast-iron, steel, brass, zinc, and other easily fusible metals by founding. When the approximate form has been given, we have seen how to produce small changes by chipping and filing. We have now to learn another method of building up complex forms by uniting simpler pieces, which partakes in part of the nature of welding, and in part of that of casting.

Soldering is uniting two pieces of metal by means of another metal. This other metal may be, first, one which melts at a lower temperature, and which adheres closely to the two pieces or partially combines with them and thus joins them together; or, secondly, it may be the same metal as that of which the two pieces are composed. In the first case the operation is very much like that of gluing. It is called "soft soldering" when the

solder is an alloy of tin and lead, sometimes with the addition of bismuth to make it more fusible; and "hard soldering" when a less fusible material is used, as gold, silver, copper, or an alloy of tin lead, and zinc, called spelter solder. In the second case, when the pieces are joined by a portion of the same metal, the operation is more analogous to welding, and is called "burning" or "brazing." A few examples will make clear the nature of the operations and the mode of proceeding.

For a first exercise, join with soft solder two pieces of brass in the manner shown in Fig. 82. File the edge of the piece A straight and square. Scrape or file the surface of B clean, where A is to join it. The two are now ready for the solder.

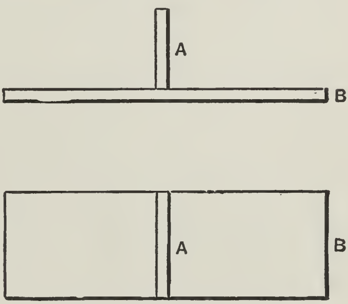

Fig. 82. (Full size.)

As in welding, so in soldering, it is necessary that the two surfaces should be clean and free from oxide. A flux is therefore used as in welding, to carry off the oxide that will be formed on the surface when heated, as well as any dirt that may be there. Various fluxes are used for different kinds of work, as borax, sal ammoniac, resin and muriate of zinc. For this exercise we will use the last. It is prepared by dissolving scraps of

zinc in dilute hydrochloric acid. A small wide-necked bottle of this solution is kept on the bench ready for use. It should have a piece of iron wire thrust through the cork and dipping down into the fluid. With this a drop or two of the fluid can be applied to the surface of a piece of metal as needed. Or, a stouter piece of wire may be fitted with a wooden handle and used for this purpose, as well as for "tinning" small surfaces, such as those of this exercise. For the latter purpose the wire must itself be tinned at the end. To tin the wire, dip it into the solution, then hold it in the flame of the Bunsen burner, the outer tube of the burner being turned so as to admit plenty of air, giving a blue flame. If the air supply is insufficient, the flame will be yellow and smoky, and not so hot. Rub the end of the wire with the solder-stick, using the "tin-solder" compound of 3 parts of tin to 2 of lead, or 2 of tin to 1 of lead. The solder will adhere to the surface wherever it is clean. If there is any spot where it does not adhere, it must be cleaned with the file or a piece of sandstone, and the operation repeated. With the tinned wire we can now tin the surfaces of the brass. Hold the piece A in the flame with pliers. Apply a drop of the flux to the edge with the tinned wire, and as it boils off rub the wire to and fro along the edge till the latter is covered with a bright

Exercise 45. Soldering brass on brass with soft solder.

clean layer of the solder; or, touch it with the solder stick till a drop of the solder adheres, and then spread it along the edge with the wire. With-

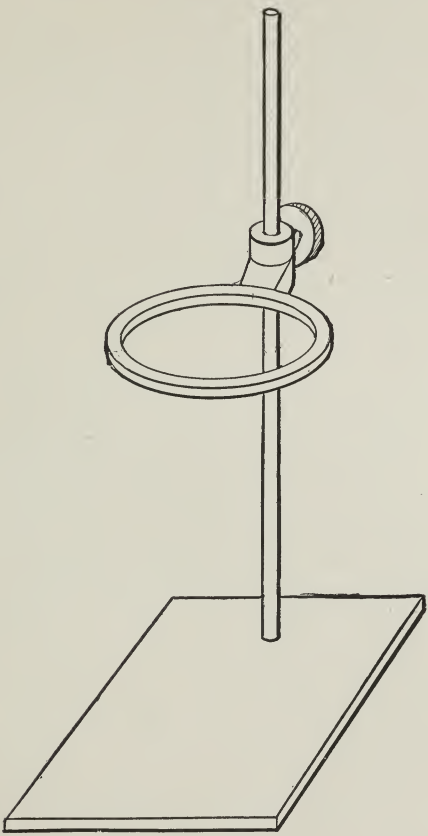

FIG. 83.

draw it from the flame and let it cool. Tin in the same way the portion of B on which A will rest. The two surfaces will now unite, if held together

while the solder is melted. They may be held together in various ways.

1. The piece B may be laid on a retort-stand, Fig. 83, and the piece A set up on it at the proper place. The flame being then applied below B, the solder will melt, and then, the flame being removed, the piece will cool. As the two surfaces of the solder are somewhat round, it is difficult to make the thin piece A stand upright. It may be held down during the melting with a pointed wire, or still better by means of a wire spring of hard brass, as in Fig. 84. In either case it will be best to file the two round surfaces of the solder flat before putting them together. Or,

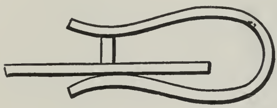

FIG. 84.

2. The pieces may be held, one in each hand, with a pair of pliers, and pressed lightly together in the flame till the solder melts, and then removed to cool. Or,

3. Clamped together by the spring as in case 1, they may be held in the flame with a pair of pliers, and soldered and cooled as before.

With such light pieces as these the last method will probably be found the most convenient. If the piece A were considerably heavier, and broader at the base, its own weight would keep it in position, and no special device would be needed for holding it.

The two pieces of this exercise may be soldered without previous tinning, if the surfaces are thoroughly clean. Hold the pieces together with a spring, as before. Taking B in the pliers with the left hand, put a drop or two of flux, and a few small chips of solder cut off with a knife, in each of the angles. Heat the pieces in the flame. First the flux will flow into the joint and afterwards the solder. If the solder does not spread along the whole length of the joint, draw it along with the end of the fine wire which is in the bottle. Cool as before.

In whichever way the pieces are prepared and heated, the principal points to be heeded are:

1. To have the surfaces quite clean.

2. Not to allow the pieces to be displaced by the boiling of the flux or the melting of the solder.

3. Not to hold the pieces in the flame longer than is necessary to melt the solder, as overheating burns the solder and weakens the joint.

4. Not to disturb the pieces till the solder has "set," or hardened. The moment of setting can generally be observed by watching closely. At this moment the bright surface of the solder becomes dulled by the formation of a multitude of minute wrinkles as the metal contracts. The cooling may be hastened, in the case of very light pieces, by blowing, and in that of heavier pieces by applying a few drops of water.

5. Not to use too much solder. Besides being wasteful, this fills up the angle, and the excess will have to be filed away to make a neat job.

Where gas cannot be used, the exercises of this lesson can be performed with a blow-pipe (as in Lesson XXIV) or with a blast-lamp, Fig. 85. This is an alcohol lamp, A, which burns under a vessel of alcohol, B. The alcohol in B boiling,

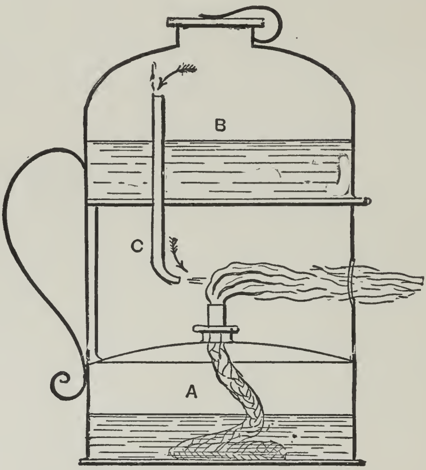

Fig. 85.

drives off first the air and then alcohol vapor through the tube C, thus blowing a strong blast through the flame of the lamp, and shooting out a tongue of hot flame which can be directed on the work. If the lamp alone is used, and the blast is produced by blowing with the mouth through a bent tube, the instrument becomes an ordinary blow-pipe.

It is obvious that such a joint as that in the last exercise cannot have any very great strength. It will nevertheless often be useful when, as in experimental work in the physical laboratory, it is desired to put two pieces together quickly, and strength is not important.

Let us now look a little more closely into the strength of a soldered joint. Join two pieces of

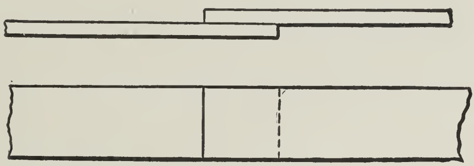

Fig. 86. (Full size.)

brass with a "lap-joint" as in Fig. 86, cleaning and tinning the surfaces, and holding them together in the flame with a pair of pliers. Put the jointed strip into the small testing-machine (Woodworking, Fig. 8, p. 19), and pull till the joint breaks. Record the force used. Put one of the pieces into the machine and break it, and record the force used. Find,

Exercise 46. Testing a soldered joint.

1. How many times stronger the brass is than the soldered joint.

2. How many times stronger the brass is than a soldered joint of the same area as the cross-section of the brass; and thence,

3. How large the joint should be to be just as strong as the brass.

Then make another joint of the same kind, with a lap just sufficient to make the joint as strong as the metal. Test the metal and the joint in the machine and record the result. You will know henceforth how large a joint surface to allow, with this kind of solder and this kind of brass, if you wish the joint to be as strong as the metal. Stronger than the metal it is not worth while to make it.

LESSON XXIII.

SOLDERING. THE SOLDERING-IRON.

When the pieces are large, it is convenient and usual to heat only the part which is to be soldered, leaving the rest cool. This is done with the "bit" or "soldering-iron."

Exercise 47. Tinning a soldering-iron.

The iron is first to be tinned. Heat it to a dull red on a charcoal fire, or over a large Bunsen burner. File the sides bright, quickly. Rub it on a piece of board sprinkled with powdered sal-ammoniac or resin, and then on a plate of copper on which are some chips of solder. Wipe it clean with a rag. If you have allowed it to fall below the temperature at which solder melts, the operation will fail, and reheating will be necessary. If afterwards, in using the soldering-iron, you overheat it, the tin will burn off, and you will have to tin it again.

We will now make a joint somewhat like that in Exercise 45, but longer and stronger, and between two sheets of tin (that is, tinned iron), arranged as in the isometric sketch, Fig. 87. Mois-

ten the angle c between the two pieces with flux, or sprinkle it with powdered resin. Scatter along it small chips of solder. Hold the piece A down firmly at one end with the end of a file, or any pointed tool, and melt a drop of solder in the angle. This will fasten or "tack" the piece at one end. Tack it in the same way at the other

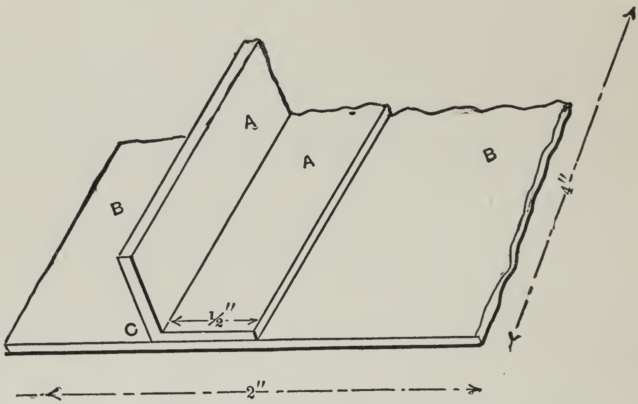

Fig. 87.

end. This will hold it in place while you finish the job. Hold the piece level, or inclined in such a way that the solder shall run into the joint. Draw the bit slowly along the angle, melting the solder and causing it to run into the joint. If any part is missed, go over it again in the same way.

Exercise 48. Soldering with the soldering-iron. Tin on tin.

The two sheets of metal in the last exercise are in planes perpendicular to each other. In this case, when the joint is at the edges of both pieces,

it may be made as in Fig. 88, A or B. The joint A would be tacked and soldered as in the exercise just finished. In B the lower piece should be closed tightly on the upper with the hammer, and then soldered along both the exterior and the interior angle. The manner of bending the sheets for this exercise and the last will be explained in connection with the next.

When the two sheets are to be in the same plane, there are several ways in which they may be joined. These are shown in Fig. 89.

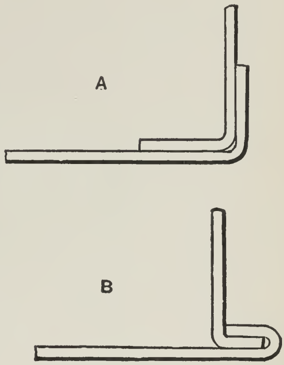

FIG. 88. (Full size.)

The joint A is called the lap-joint. It needs but to be tacked at two or three points, as in Exercise 48, and soldered as there described.

B is a "cramp-joint." The edge of the left-hand piece is thinned almost to a knife-edge by hammering on a small anvil. The edge of the other is nicked obliquely with the shears, and the pieces between the cuts are turned alternately up and down. The thinned piece is pushed into the V-shaped space thus made, and the "cramps" are hammered down on it. It is then tacked and soldered.

The edges of the two pieces in C, as well as in B, Fig. 88, and A, Figs. 87 and 88 are prepared

on a tool called the "hatchet-stake," Fig. 90, which is set in a hole in the top of the work-bench. The sheet is laid on the edge AB at a proper distance from the edge of the sheet, and turned over by blows of a flat mallet, the edge

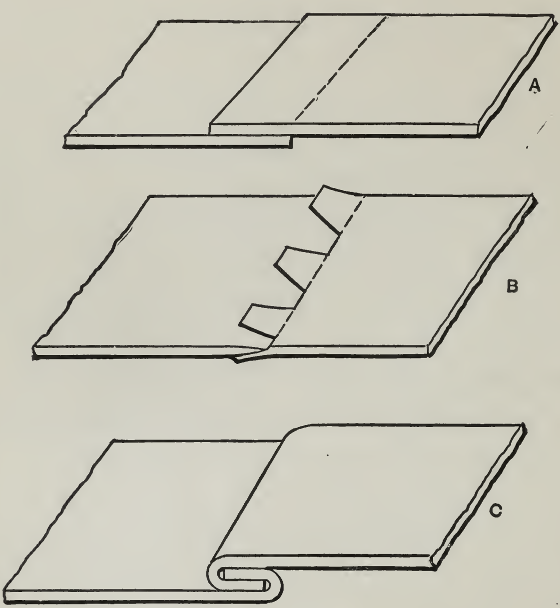

Fig. 89. (Scale ½.)

being either turned up at right angles to the sheet, or doubled over on it, according to the kind of joint proposed.

As an exercise in this kind of soldering, and one in which a water-tight joint is required, make a cubical box of tin or sheet brass, whose edges

shall have the length of one decimeter exactly, inside. Such a vessel will be a "liter" measure.

Exercise 48. A cubical vessel.

The bottom must be cut to the form and dimensions shown in Fig. 91, A, and must be bent upward, at right-angles, along the dotted lines. The sides are shown at B, and are to be bent at right angles along *ad*, *dc*, and *cb*, and doubled along *ab*. The notches

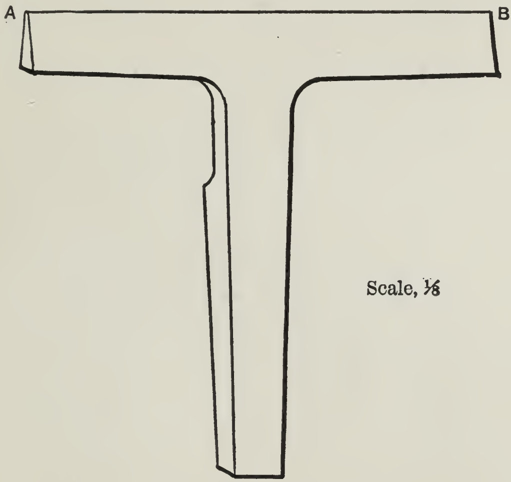

FIG. 90. (Scale $\frac{1}{8}$.)

at the corners show where pieces must be cut out to let the upturned edges lie flat. The dimensions in the figure are those that all the pieces should have if the material had no thickness. Owing to the thickness of the metal these must be slightly altered, and the amount of the alteration will depend on the thickness. If the bottom is

put on outside of the other pieces, it will be necessary to make its inside dimensions larger by twice the thickness of the metal. Furthermore, as

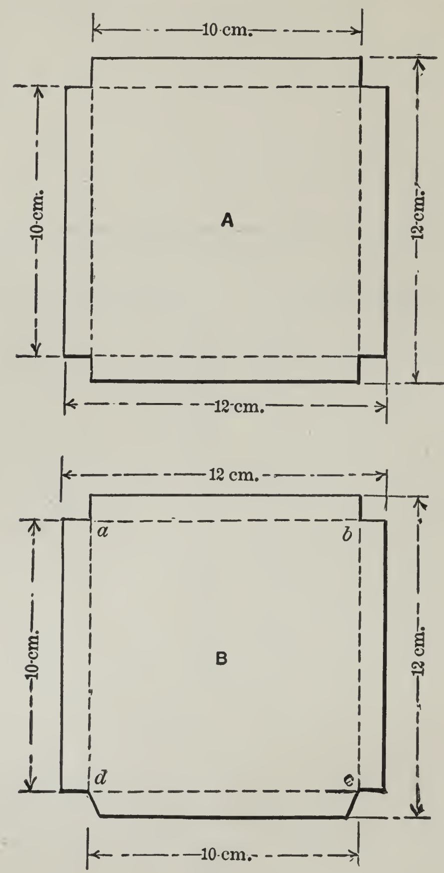

FIG. 91.

two opposite sides of the vessel are turned over the other two, they also must be made wider by twice the thickness, and all the sides must be higher by

once the thickness. It will be well to cut out the pieces in card-board and put them together, to assure yourself that you can cut them correctly; make the proper allowance for thickness, and put them together properly. Then mark out the pieces with a "scratch-awl," Fig. 92, and cut them out with the shears. Bend the edges of the bottom upwards, the upper edges of the sides outwards, and the other edges inwards, over the hatchet-stake, being careful to keep them quite straight, and not to bruise the sheets. Set the five pieces together to assure yourself that they fit properly. You will now discover that the overturned edges of the larger side-pieces, overlapping the smaller side-pieces, prevent the bottom from going on, and four small square pieces have to be cut out from the bottom of these. This cut is not shown in the sketch, and you must determine for yourself its proper size and shape. Cut out these pieces with small shears, being careful not to make the cuts too large.

FIG. 92.

Now lay one of the larger sides on your bench, and join the two narrower sides to it as in Exercise 48, Fig. 87, being careful, in soldering, not to miss any portion of the joint. Lay the other large side on the bench, and repeat the same operation. The four sides are now fastened to-

gether, and ready for the bottom. Set the bottom in place, and solder it in the same manner.

When the vessel is finished, all the angles should be perfectly square, all the faces flat, and all the joints perfectly water-tight and perfectly smooth inside and outside, showing no places without solder and no lumps of unnecessary solder, and the internal dimensions should be exactly 10 centimeters each way.

LESSON XXIV.

SOLDERING. BLOW-PIPE.

Excrcise 49. Use of the blow-pipe.

When a very small piece is to be soldered to a much larger one, it is often convenient to use the blow-pipe instead of either the Bunsen burner or the soldering-iron, as with this an intense heat can be applied on a very small area. As an example of such a joint we will solder an electrical "binding-post," A, Fig. 93, to a brass plate B. Take a piece of sheet brass about 5^{cm} long, 3^{cm} wide, and 3^{mm} thick. Make the end of the post flat, and clean with the file. Scrape or file the portion of the plate at which the post is to be attached. Lay the plate on any convenient support, and set the post on it. Moisten the angle all round with a drop or two of the zinc solution, and lay a few granules of solder there. Set the Bunsen burner by the side of the work, with the bottom of the flame about on a level with the plate. Turn the outer tube of the burner so as to shut off the supply of air at the bottom, giving a yellow instead of a blue

flame, and less heat. Holding the blow-pipe in the right hand, with the tip just outside the flame, direct the current of air from the mouth through the lower part of the flame. This will produce a long slender jet of blue flame, in which the temperature is very high. Direct this on the base of the post and the plate adjoining. The flux will quickly boil away, and the solder will melt and

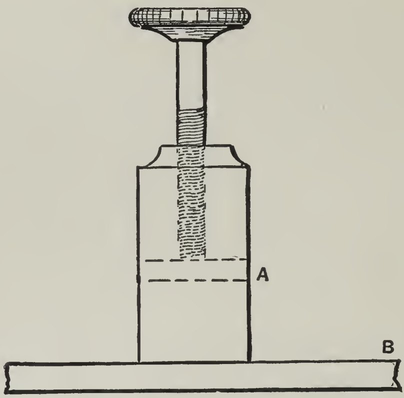

Fig. 93. (Full size.)

run into the joint. Remove the blow-pipe, and let the work cool.

In making a small joint in this way you must be careful—

1°. Not to use too much solder.

2°. Not to let the flame play on parts of the metal which need no heat, as it discolors them.

3°. Not to continue the heat longer than necessary.

4°. Not to let the small piece be displaced by the boiling of the flux. Hold it down with a piece of wire if necessary.

There is sometimes a still greater necessity than in the last exercise of preventing the spread of heat to other parts than that at which the joint is to be made. A good example of this is in the case of the soldering of a spring A, such as you made in Exercise 36, to the plate B, Fig. 94. If

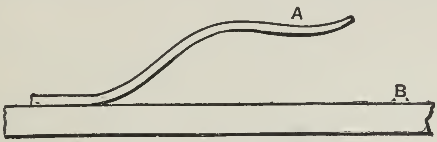

FIG. 94. (Full size.)

the spring is overheated, its temper will be "drawn," and the spring spoiled. This may be avoided by "sweating" the spring on the plate.

Exercise 50. Sweating a Joint.

Tin the plate, at the proper point, over the Bunsen flame. Then hold the spring in place by means of a clamp A, Fig. 95, made by filing or sawing a slit in a piece of brass or copper. Apply flux and bits of solder along the edge of the joint. Hold the clamp, not the plate, in the Bunsen flame, and watch the solder closely. The heat conducted along the clamp will reach the plate and melt the solder. As soon as this happens, remove the work from the flame, and cool it off before there is time for the spring to be heated.

The exercises 45 to 50 illustrate the principal methods of uniting small pieces by means of soft solder, or such as melts at temperatures below about 450° F. Joints with such solder are, as you have found, not very strong, and when great strength is important, or when the joint may be exposed to much heat when it is used, a hard solder must be employed. Hard solders, instead of being made of lead and tin, are commonly made

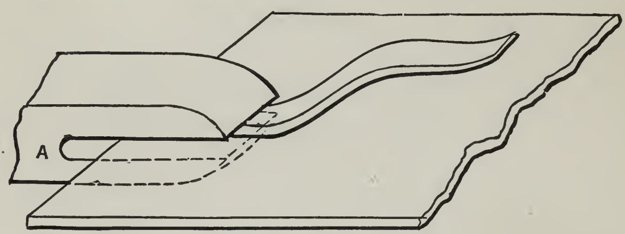

FIG. 95. (Full size.)

of copper and zinc, or of copper and silver, called silver solder. They require a higher temperature to fuse them, and the management of them, which is somewhat more difficult than that of the soft solders, may be deferred to a later stage in your study, along with brazing and burning.

ALPHABETICAL INDEX.

Date Due
